ECONOMIC GEOLOGY

VOL. XXVIII JUNE, 1933 NO. 4

ORE DEPOSITS OF THE UNITED STATES IN THEIR RELATION TO GEOLOGIC CYCLES.[1]

B. S. BUTLER.

CONTENTS.

Introduction 301
Geologic Cycles 302
Sequence of Events 303
Position of Metal Deposits 304
Periods of Metal Concentration 304
Distribution of Deposits as Controlled by Positive and Negative Areas 305
Pre-Cambrian Cycles 305
Appalachian Paleozoic Cycle 311
Cordilleran Cycle 317
Rocky Mountain Cycle 321
Comparison of Pacific and Atlantic Belts 322
Character of Mineralization at Different Stages in Igneous Cycles .. 324
Summary 325

INTRODUCTION.

DURING the coming weeks many of us will be seeing, in a hasty way, the geology over wide stretches of the United States. A most excellent series of guide books has been prepared to assist us, and a splendid geological map of the United States is available. Each guide book covers a limited area, but they are supplemented by more general discussions and certain features of the

[1] Address of the retiring president read before the Society of Economic Geologists at the Princeton meeting, July, 1933.

geology will be further supplemented by papers presented to the International Geological Congress that will correlate the different areas. They are also supplemented by papers published by the American Institute of Mining and Metallurgical Engineers in the Lindgren volume on the geology and ore deposits of the Cordilleran region of the United States.

It is my purpose to present to you some of the broader relations of ore deposits to other geological features and the process of ore deposition to other geological processes that may be of interest in considering the various ore deposits that will be visited. I am offering you nothing distinctly new, but that does not mean that it is all true. Of its truth you will judge for yourselves.

That the area of the United States includes abundant and varied mineral deposits is not a matter of accident or chance. The processes that concentrate elements into mineral deposits are only special features of the processes that have built the continents. The area of the United States occupies a central cross section of the North American Continent and it is but natural that it should contain within its borders most of the products that have resulted from processes of continent building. Were the area to be separated into several political divisions none would have both an abundance and a variety of mineral products.

GEOLOGIC CYCLES.

Geological processes, like many other processes, work in cycles and at stages in these cycles certain concentrations of elements are affected. Some are concentrated during the weathering of land surfaces, as the lateritic iron, manganese, clay and aluminum deposits. Some are concentrated during transportation as the placer deposits, and some are deposited in the sea as chemical or biochemical deposits, such as salt, limestone, and phosphate. Under proper conditions vegetable and animal matter that are accumulated pass through biochemical and geochemical processes to produce coal, oil, and natural gas.

Another type of concentration results from the crystallization of bodies of fluid rock material. Some minerals crystallized early, with concentration of the elements contained in them, and

also a residual concentration of other elements in the solution from which the minerals crystallized.

We sometimes think of and discuss such widely differing processes of concentration as though they were entirely independent, rather than that they are all a part of a great cycle and a part of the process of continent building.

Likewise we may think of striking geological events, such as mountain building, as independent of other less striking events. We separate and date our geologic periods by such events, very properly, but sometimes without quite realizing that each is only an event in a broad cycle. Just as in human affairs, we designate political events by revolutions and wars that usually only mark a stage in a political cycle.

Sequence of Events.—The geologic cycle is recognized as having a definite sequence of events which have been repeated from far back in pre-Cambrian to recent time. In this paper it is my purpose to point out particularly the relation of events of the geological cycle to the formation and distribution of metallic ores.

How the first geologic cycle started I shall not say. It is sufficient for a beginning that a positive area, a geanticline or an area standing relatively high and subjected to erosion, is bordered by a negative area, a geosyncline or a relatively low area that is receiving sediment eroded from the positive area. The positive area tends to rise as it is lightened by material removed by erosion and the negative area tends to sink as it receives added loads of sediment. The balance is maintained by a deep flow from the negative to the positive area according to the well known and quite generally accepted theory of isostatic adjustment.

This process goes on for long geologic time with the areas maintaining their relative positions. At some stage, however, the crust of the basin of sedimentation becomes so weakened by being forced downward into the zone of flowage that it gives way, initiating a period of folding and faulting in the geosyncline and along the boundary of the positive and negative area. In some basins folding or faulting started before there had been very great accumulation of sediments.

Closely following the start of the folding and faulting and in

some instances before such structures are conspicuous, there is a period of intrusion, extrusion, or both, of basic magma. Much of the extrusion is submarine, as the geosyncline is low and receiving sediments. This stage may start early, be of long duration, and yield alternations of sediment and lavas. Next comes a period of intensive folding and overthrust faulting that is followed by the intrusion of batholithic bodies that crystallize to form rocks of intermediate to granitic composition. With the folding, intrusion and solidification of the batholithic masses the area rises, it is no longer a region of marine sedimentation, and the climax of structural and igneous activity of the cycle is reached. Following the climax, deformation and igneous activity continue at intervals with generally decreasing intensity for a long time.

Position of Metal Deposits.—With the present lack of agreement as to the origin of certain ore deposits it is not possible to place all deposits in a grouping that will be generally accepted. I am placing them in the positions that to me seem most logical.

There are some apparently rather isolated deposits such as the Homestake gold deposits of South Dakota and the Franklin Furnace zinc deposits of New Jersey that I prefer not to classify.

PERIODS OF METAL CONCENTRATION.

In the geologic cycle the formation of metal deposits is quantitatively insignificant, but it is of much geological interest and also of much practical importance. In a broad way metal concentration during the cycle can be grouped into three periods. First, concentrations from weathering and erosion yielding mainly (*a*) lateritic iron, manganese, and aluminum deposits, (*b*) placer deposits, (*c*) some bog iron and manganese deposits, and (*d*) deposits in the sea which probably includes some iron deposits. Most of the lateritic and placer deposits of past cycles were destroyed by further erosion and were not buried and preserved.

This group is important in the gold placers, the lateritic iron, manganese and bauxite deposits, and some bog iron deposits of the present erosion cycle. Some of a slightly earlier period, as the Tertiary auriferous gravels of California, have been in part buried

beneath lavas, but, since in the main the deposits of earlier cycles have not been preserved, this group will not be further discussed.

Second, concentration during the period of intrusion and extrusion of basic magma which in many places was accompanied by the emission of much iron and silica that was deposited as chemical or biochemical sedimentary iron formation.

Third, concentration following the intrusion of the batholithic bodies in a period of metallization that yielded a variety of deposits formed by the solutions expelled from the magmas as they crystallized and in elements that segregated in the magma chamber by crystallization of minerals.

DISTRIBUTION OF DEPOSITS AS CONTROLLED BY POSITIVE AND NEGATIVE AREAS.

In position the lateritic and placer deposits of the first group form on land surfaces undergoing erosion, and in due time are destroyed by continued erosion. The iron formation of the second group forms near the boundary of the positive and negative area where the structural collapse begins, but may deposit in shallow seas extending for some distance from the boundary into the negative area. Perhaps a sea bordering an area of gentle relief that is receiving relatively little land sediment is particularly favorable to the accumulation of iron formation. The third group, associated with batholiths, also forms near the boundary of the negative and positive areas where the structural collapse is greatest, but may extend into both the negative and positive areas.

Pre-Cambrian Cycles.

The earliest general distribution of positive and negative areas in North America that paleogeographers have outlined definitely is for the late Proterozoic (Fig. 1) but it is recognized that this period is not early in earth history and that processes of continent building had long been active. It will be noted that in this period the negative area that bordered the great positive Canadian shield area covered the Lake Superior region, and a negative area included the Rocky Mountain region in the western United States.

For the Lake Superior region this period might be termed the

Huronian-Keweenawan cycle. It was during this cycle that most of the great iron deposits formed, followed by the copper deposits of Lake Superior and the copper-nickel and cobalt-silver deposits of Ontario.

The source rocks of the iron ore deposits of the Lake Superior region [2] are commonly considered to be of sedimentary origin and include greenalite (ferrous silicate), ferrous carbonate with some hematite and in some areas magnetite, interbedded with cherts and some shales or slates. This primary iron formation varies in composition and in mineralogy from place to place and in the different districts, but the greenalite rock of the Biwabic formation which may be taken as an example [3] ranges in free silica from 33 to 48 per cent. and total silica from 46 to 61 per cent.; in ferric oxide (Fe_2O_3) from 6 to 15.0 per cent.; and in ferrous oxide from 10 to 30 per cent. In the primary iron formation silica far exceeds iron and the ore has resulted from later enrichment of this material.

The iron formation in some of the iron ranges is closely associated with basic igneous rock of essentially the same age and Van Hise and Leith [4] have concluded that the iron salts were transferred from the igneous rocks to the sedimentary iron-bearing formations partly by weathering when the igneous rocks were hot or cold, but also by direct contribution of magmatic waters from the igneous rocks and perhaps in small part by direct reaction of the sea waters upon hot lavas. Presumably the silica of the iron formation had a similar origin. The idea of direct contribution by magmatic emanations of silica and iron to the waters from which the iron formations were deposited has been advocated by other geologists, both in the United States and Canada, as Hotchkiss [5] and Collins and Quirk [6] for example, and

[2] Van Hise, C. R., and Leith, C. K.: Geology of the Lake Superior Region, U. S. Geol. Surv. Mon. 52, 1911.

[3] *Op. cit.*, p. 167.

[4] *Op. cit.*, p. 516.

[5] Hotchkiss, W. O.: The Lake Superior Geosyncline. Bull. Geol. Soc. Amer., vol. 34, p. 675, 1923.

[6] Collins, W. H., and Quirk, T. T.: Michipicoten Iron Range. Canada Geol. Surv. Mon. 147, pp. 1–141, 1926.

Moore and Maynard [7] are inclined to regard igneous activity as an important factor especially in the silica-rich deposits. Others, as Gruner,[8] Grout [9] and Broderick [10] consider that much, at least, of the iron and silica was derived by weathering from the basic rocks. Gruner [11] thinks that the concentration of the iron formation to iron ore was accomplished by magmatic agencies. All are apparently agreed that the iron formation is closely associated with the basic lavas in time of formation, whether derived from it by weathering or by direct magmatic contributions or by both.

Hotchkiss [12] has offered an interesting summary of the late pre-Cambrian events of the region and suggests the slow rise of a batholithic mass from great depth through a long geologic period. It is his conception that it was rising through all Huronian time and that its first surface expression was the doming of the area over it with resultant erosion. The early contributions to the surface from the batholith were basic lavas and silica-iron solutions which together furnished the material for the iron formations of the Huronian. Between long periods of quiet these were expelled intermittently, giving several horizons of iron formation. The final expression, when the mass had closely approached the surface, was the extrusion and intrusion of great quantities of magma in Keweenawan time. This was followed by the deposition of the copper deposits of the region and probably by the copper-nickel and silver deposits of Ontario.

It may well be asked why the great series of Keweenawan lavas

[7] Moore, E. S., and Maynard, J. E.: Solution, Transportation and Precipitation of Iron and Silica. ECON. GEOL., vol. 24, pp. 272–303, 363–402, 506–527, 1929.

[8] Gruner, J. W.: The Origin of Sedimentary Iron Formation. The Biwabic Formation of the Mesabi Range. ECON. GEOL., vol. 17, pp. 407–460, 1922.

[9] Grout, F. F.: The Nature and Origin of the Biwabic Iron-bearing Formation. ECON. GEOL., vol. 14, pp. 452–464, 1919.

[10] Broderick, T. M.: Detailed Stratigraphy of the Biwabic Iron Formation. ECON. GEOL., vol. 14, pp. 441–451, 1919. Economic Geology and Stratigraphy of the Gunflint Iron District. *Idem.*, vol. 15, pp. 422–452, 1920. Grout, F. F., and Broderick, T. M.: Organic Structures in the Biwabic Iron-bearing Formation, Amer. Jour. Sci. (4), vol. 48, p. 199, 1919.

[11] Gruner, J. W.: Hydrothermal Oxidation and Leaching Experiments: Their Bearing on Origin of Lake Superior Iron Ores. ECON. GEOL., vol. 25, pp. 697–719, 837–867, 1930.

[12] *Op. cit.*, p. 673.

should not have associated iron formation? The answer may be that there was no nearby or blanketing body of water such as existed during the Huronian volcanic activity. The Keweenawan series was accumulated on a land surface, perhaps far from shallow bodies of water that may be essential to the deposition of extensive bodies of iron formation. The Huronian volcanic activity was largely submarine and the emanations from the crystallizing basalt or from hot springs and fumaroles were added directly to the waters with little admixture of detritus.

Pre-Huronian Cycle.—Iron formation and iron deposits including those of the Vermillion range of Minnesota, are numerous though not of great importance in the Kewatin rocks which are separated from the Huronian by a great unconformity and evidently belong to an earlier cycle.

Following the late Proterozoic, the boundary of the Canadian Shield moved further southward. It is possible that before Huronian time the boundary was farther north and that the shield was progressively enlarging. The events in what may be termed the Kewatin-Laurentian cycle are not as clear as those of the Huronian-Keweenawan and not well represented south of the international boundary, but it seems to show the same sequence, namely extrusion of great volumes of basic lava partly, at least, submarine, together with the deposition of interbedded iron formation. This was followed by the intrusion of granitic batholiths with which the gold and other non-ferrous deposits of Ontario of pre-Huronian age are believed to be associated. Why gold should be the most valuable metal in the batholithic stage of the earlier period and copper, nickel and silver in the later is beyond the scope of this paper.

Pre-Cambrian of the Rocky Mountain Region.—The close correlation of the pre-Cambrian rocks of the Lake Superior region and those of the Rocky Mountain region is probably not yet possible, but it is likely that both early and late pre-Cambrian are present in the Rocky Mountain region. It may be noted that most of the pre-Cambrian ore deposits of the western United States fall within the areas that Schuchert has indicated as geosynclinal in late Proterozoic time (Fig. 1).

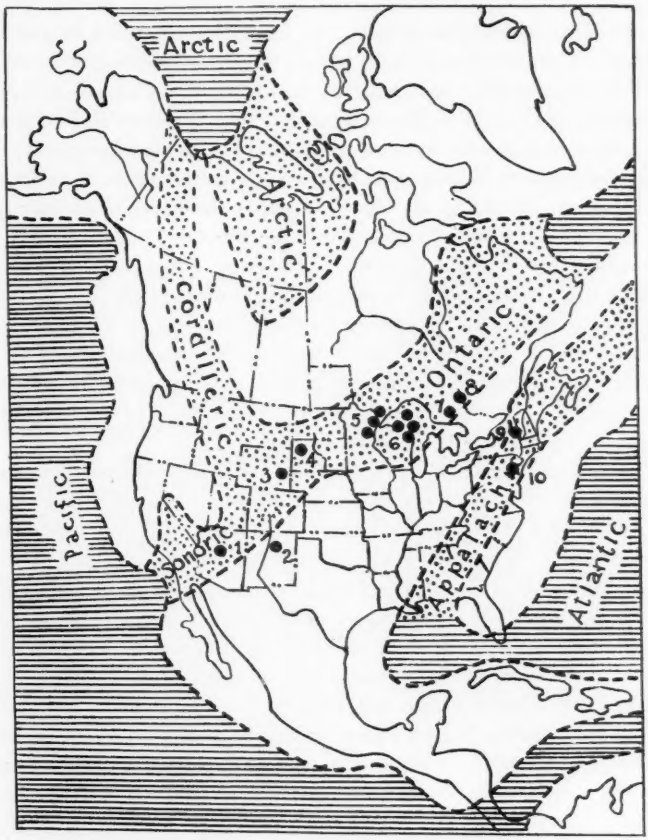


FIG. 1. North America during the later Proterozoic, showing geosynclines (stippled) and pre-Cambrian mineral districts. After C. Schuchert. 1. Jerome, Ariz. 2. Pecos, New Mexico. 3. Sunrise, Wyoming. 4. Whitewood, So. Dakota (Black Hills). 5. Cuyuna, Mesabi. 6. Gogebic, Calumet, Marquette, Menominee. 7. Sudbury. 8. Cobalt. 9. Adirondack. 10. Franklin Furnace.

In Wyoming, deposits of pre-Cambrian iron ores have already yielded a considerable output. At Hartville, according to Ball,[13] the ores are associated with intrusive rock, with limestone and with jasper rock. Ball regards the workable deposits as of secondary origin. T. B. Stone, geologist for the Colorado Fuel and Iron Company, who has studied the deposits in their present state of development, as reported by T. S. Lovering in the Lindgren volume of the A. I. M. M. E., regards the deposits as mainly primary and similar to both the Lake Superior deposits and the neighboring Seminole deposits.[14] Lovering states that the Seminole iron formation is strikingly like that of the Vermillion Range of the Lake Superior region. It consists of iron bearing jasper and is thought by Lovering to have formed as spring deposits later modified by metamorphism. In support of this view he cites the chemical resemblance of the deposits to present day spring deposits in the Yellowstone park.

The iron formation and schists are cut by dioritic and granitic intrusions with which are associated deposits of copper, gold, and arsenic. In Wyoming there seems to have been a pre-Cambrian cycle similar to those of the Lake Superior region.

Iron Deposits of Canyon Creek-Fort Apache Indian Reservation, Arizona.—The iron deposits of Canyon Creek, Fort Apache Indian reservation, Arizona, described by Burchard,[15] are similar in many respects to the sedimentary iron deposits in that they are composed of banded silica and hematite that has probably replaced the pre-Cambrian Mescal limestone and is closely associated with a diabase laccolith. Burchard suggests the diabase as the source of the ore forming solutions. In this occurrence there is no record of later intrusive rocks with associated sulphide deposits.

There are numerous deposits of sulphide ores in the Rocky Mountain region with which there are no recognized earlier associated iron-formations. Most of them are associated with basic schists of probable igneous origin that are cut by later granitic

[13] Ball, S. H.: U. S. Geol. Surv. Bull. 451, 1911.

[14] Lovering, T. S.: The Rawley, Shirley and Seminole Iron-Ore Deposits of Carbon County, Wyoming. U. S. Geol. Surv. Bull. 811, pp. 219–235, 1929.

[15] Burchard, E. F.: Iron Ore on Canyon Creek, Fort Apache Indian Reservation, Arizona. U. S. Geol. Surv. Bull. 821, pp. 51–68, 1931.

intrusives. These relations are illustrated by the deposits of the Jerome-Prescott region, Arizona,[16] the Pecos region, New Mexico,[17] and several districts in Colorado.

Pre-Cambrian banded iron deposits in the Llano, Texas, district are associated with basic schist and cut by later granitic intrusives as described by Paige,[18] who, however, does not regard the iron formation as closely associated in origin with the basic schists.

Appalachian Paleozoic Cycle.

The pre-Cambrian history of the Appalachian region will not be considered here. Schuchert's paleogeographic maps indicate that during the Paleozoic (Fig. 2) the present site of the Appalachian mountains was a geosyncline with a land mass to the east and a low central land mass connecting with the Canadian shield area was alternately above and below the sea. This condition prevailed until the close of the Paleozoic, when the Appalachian mountains were formed by the folding and faulting of the sediments in the eastern part of the geosyncline and great batholithic bodies of granitic rock were intruded along the eastern margin of the folded area. Events were doubtless not contemporaneous throughout the Appalachian belt. Paleozoic folding and igneous activity in the northern Appalachian area began as early as Cambrian[19] and extensive intrusion occurred by middle Paleozoic. Jonas[20] states that "there is no evidence that intense folding and metamorphism comparable to the Taconian in New England affected the Appalachians southwest of northeastern Pennsylvania in late Ordovician time."

Sedimentary Iron Ores.—The most productive iron ores of the Appalachian area are the Wabana ores of Ordovician age in New-

[16] Lindgren, W.: U. S. Geol. Surv. Bull. 782, 1926.

[17] Kreiger, Philip: The Zinc Lead Deposits of Pecos. ECON. GEOL., vol. 27, p. 468, 1932.

[18] Paige, Sydney: U. S. Geol. Surv. Bull. 450, p. 15, 1911.

[19] Prindle, L. M., and Knopf, E. B.: Geology of the Taconic Quadrangle. Amer. Jour. Sci., vol. 24, pp. 257, 302, 1932. Emerson, B. K.: Geology of Massachusetts and Rhode Island. U. S. Geol. Surv. Bull. 597, 1917.

[20] Jonas, A. I.: Structure of Metamorphic Belt of Southern Appalachians. Amer. Jour. Sci., vol. 24, p. 141, 1932.

foundland, and the Clinton ores in rocks of Silurian age, in the United States. The difference in the age of the iron ores in the two areas seems to correspond to the difference in the period of the geologic cycle to the north and to the south.

The Clinton ores in general follow the Appalachian range from New York to Alabama and lie to the west of the old pre-Cambrian area and the great zone of batholithic intrusions of Permian age that has been outlined by Keith. There has been much discussion as to the origin of the Clinton iron deposits but it now seems to be the prevailing opinion that they are sedimentary deposits. The source of the iron is generally attributed to weathering of the rocks of the old pre-Cambrian land mass that bordered the basin of deposition to the east. However, no one has as yet offered a completely satisfactory explanation of why the deposition of iron formation should be restricted to such a very narrow stratigraphic horizon if derived from erosion of the pre-Cambrian rocks.

It would surely be presumptuous for one with only casual familiarity with the Clinton ores to question the generally accepted source of the iron, but with the conditions for deposition of siliceous iron formation in the Lake Superior region and the west coast region (the Radiolarian cherts) to be discussed later, in mind, one reads with added interest Keith's summing up [21] of the igneous activity of the Appalachian cycle:

> In the northern Appalachians these batholiths cut strata of known Carboniferous age in New England and New Brunswick, and they are known to be as late as Carboniferous in the southern Appalachians, because as a whole they show no effects of the Appalachian deformation. They are known to be overlain by Triassic strata, so that their intrusion into their present position is pre-Triassic and as late as Permian. Probably, therefore, their intrusion took place in the interval between the Permian and the Triassic. That conclusion, of course, does not mean that the intrusions were going on only at that time. Geologic thought nowadays trends in the direction of greater time for all geologic processes, and in my opinion the process of intrusion began at least as early as Ordovician and was repeated at several later epochs, culminating in the Permian. The force of these earlier intrusions was derived from masses which did not then or now reach the surface as batholiths. The presence of such action

[21] Keith, Arthur: Structural Summary in North America. Bull. Geol. Soc. Amer., vol. 39, p. 350, 1927.

is guaranteed, however, in New England and New Brunswick by the large development of volcanic action during the Silurian and Devonian, when great quantities of tuffs and flows reached the surface through the cracks in the distended crust over the batholiths.

This picture, drawn by Keith, does not differ fundamentally from that drawn by Hotchkiss for the Lake Superior region or by Lawson and others for the west coast region in which an early expression of a batholithic mass approaching the surface is the expulsion of lavas and of iron rich emanations that under favorable conditions deposit extensive but stratigraphically restricted sedimentary iron-formation.

Both in time and place the Clinton ores come where they would be expected if they are associated with the early igneous expression of the Paleozoic cycle of the Southern Appalachian region. They are, of course, equally well located for a derivation from the land mass to the east, and conditions during the Clinton may have been especially favorable to the accumulation of iron ores in the shallow seas without the addition of supplies of iron of magmatic origin. The association with contemporary igneous rocks is not obvious, as is the case for most of the iron formations, but the same can be said of some of the Lake Superior deposits, as those of the Mesabi range. Accompanying and following the batholithic intrusion at the close of the Paleozoic there was a period of mineralization in the Appalachian region, with the formation of extensive sulphide deposits of iron, copper, and zinc throughout the region. The iron-copper and iron-copper-zinc sulphide deposits are nearer to the batholithic zone, whereas the zinc sulphide replacements of limestone are to the west and more remote from the intrusions.

During the Paleozoic a branch from the Appalachian geosyncline extending westward into Arkansas, Oklahoma, and Texas is shown by Schuchert (Fig. 3) as the Ouachitic trough bordered on the south by the old land mass Llanoria, that has the same relative position to the trough that the Appalachian land mass had to the Appalachian trough.

The Ouachitic trough was folded at the close of Paleozoic time,

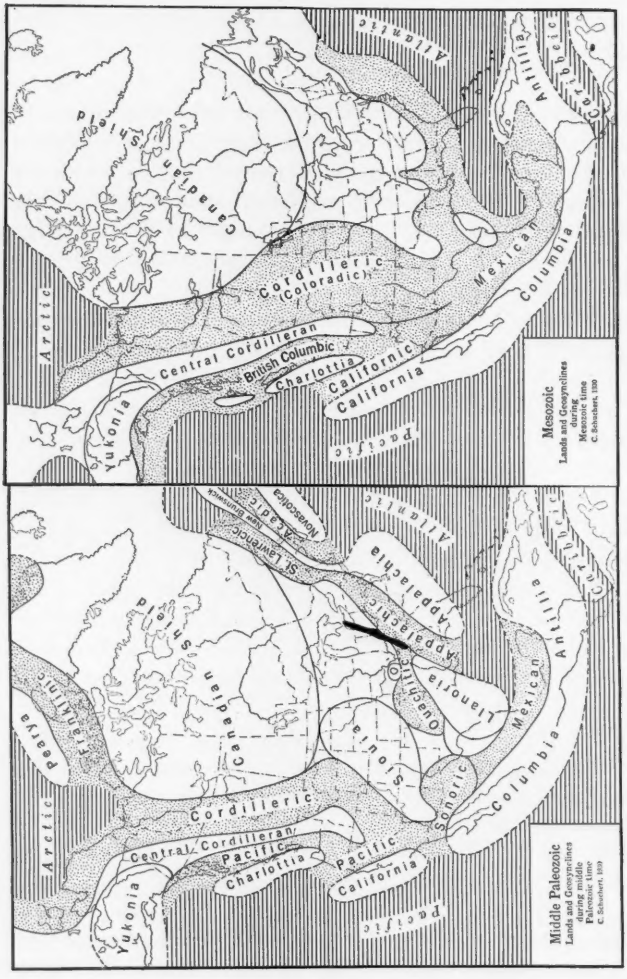


FIG. 2. North America in middle Paleozoic time, showing lands and geosynclines. After C. Schuchert.

FIG. 3. Lands and geosynclines during Mesozoic time, after Schuchert.

and Keith [22] has pointed out that the geologic history paralleled that of the Appalachian region. The belt is intruded by many igneous masses and the mineralization was similar to that in the Appalachian region but less intensive.[23] There appear, however, to be no deposits in this region corresponding to the Clinton iron ores of the Appalachian region.

Keith [24] states that one type of structure associated with the Appalachian cycle is the dome-basin structure. The domes, represented by structures like the Cincinnati arch, the Ozark uplift, and the Llano dome, are outside the more folded areas such as the Appalachian belt and Ouachita mountains.

From the viewpoint of mineral deposits the Ozark uplift is of particular interest. It is ringed around by highly productive mineral districts including, as Emmons [25] has stated, a great lead ore district in southeastern Missouri, a great zinc-lead district in Missouri-Kansas-Oklahoma, a great barite district in Missouri, and a great fluorspar district in Illinois-Kentucky, and smaller deposits to the south of the uplift in Arkansas. Keith [26] states that with the dome-basin structure normal faults of a special kind are found, that are especially well shown around the Appalachian Ozark dome in Missouri, Arkansas and Oklahoma. These faults are not due to settling and extension of the crust as is commonly believed for all normal faults, but to difference in the amount of uplift when the domes were formed. Some of these faults on the northeast side of the Ozark dome were formed in Devonian time, but most of them, on the south and west side of the dome, were of Mississippian and Pennsylvanian age.[27]

Siebenthal [28] and others have pointed out that the Ozark up-

[22] *Idem.*, p. 343.

[23] Emmons, W. H.: Sulphide Ores of the Mississippi Valley. ECON. GEOL., vol. 24, p. 230, 1929.

[24] *Op. cit.*, p. 347.

[25] *Op. cit.*, p. 271.

[26] *Op. cit.*, p. 349.

[27] Weidman, S.: The Miami-Picher Zinc-Lead District, Oklahoma. Okla. Geol. Surv. Bull. 56, p. 39, 1932. Fowler, G. M., and Lyden, J. P.: The Ore Deposits of the Tri-State District. Amer. Inst. Min. & Met. Eng., Tech. Paper 446, p. 24, 1932.

[28] Siebenthal, C. E.: Origin of the Zinc and Lead Deposits of the Joplin Region. U. S. Geol. Surv. Bull. 606, p. 31, 1915.

zoic time, after Schuchert.

time, showing lands and geosynclines. After C. Schuchert.

FIG. 4. Divisions of Permian (Appalachian) deformation. After Keith.

lift was a positive area throughout Paleozoic time, though different parts were undergoing erosion and receiving sedimentation at different times. Only in Mississippian time was the region probably entirely submerged. Igneous activity around the dome was slight, consisting mainly of small bodies of basic intrusive.[29]

It is not my purpose to enter the controversy as to the origin of the Mississippi valley mineral deposits, but in time they seem to fall in well with the mineralization at a late stage in the Appalachian cycle. The presence of abundant mineral deposits around an old positive area suggests, by analogy, similarity to other positive areas, as the Colorado plateau around which igneous activity has been greater. It should be recognized, however, that those who do not favor an igneous origin for these ores can interpret the structural relations differently.

Cordilleran Cycle.

The Cordilleran cycle may be considered as extending from the Paleozoic to the Tertiary, but may be subdivided into the Sierra Nevada cycle and the Rocky Mountain cycle. The first affected the area near the Pacific coast and culminated in the Sierra Nevada revolution at the close of the Jurassic, and the second affected more generally the present Rocky Mountain area and culminated in the Laramide revolution at the close of the Cretaceous. In both regions igneous activity, following the climaxes, has continued at intervals with decreasing force even to the present.

Throughout the Cordilleran region the Paleozoic was a period of comparative quiet with extensive erosion and sedimentation. The Cordilleran trough occupying the position of the Rocky Mountain region was already established in pre-Cambrian time and persisted through the Mesozoic, as indicated by the accompanying maps after Schuchert.

Nearer the border of the continent, Pacific basins, more or less definitely separated from the main Cordilleran basin, were early established and by mid-Paleozoic time, mild igneous activity in the form of basic flows and intrusions had begun. Such activity continued at intervals, becoming more intense and widespread in

[29] Emmons, W. H.: *op. cit.*, p. 226.

FIG. 4. Divisions of Permian (Appalachian) deformation. After Keith.

Triassic and Jurassic times and culminating in late Jurassic in the intrusion of the Sierra Nevada and Coast Range batholiths. Following this revolution vulcanism continued with decreasing intensity.

FIG. 5. Area of Jurassic (Sierra Nevada) deformation. After Keith.

Farther east there was relatively little volcanic activity in the Paleozoic or even in the early Mesozoic and the extrusions and especially the intrusions of the Laramide revolution although large were much smaller than those of the coast region. Following the Laramide revolution also, igneous activity continued with decreasing intensity through the Tertiary.

Mineralization.—Radiolarian cherts are associated with the basic lava flows of Triassic or Jurassic age along the coast region.

The occurrence of the radiolarian chert and associated rocks of the coast range has been described by Davis.[30] The age[31] of the formation is uncertain but probably Jurassic or in part Triassic. In composition it is in many respects similar to the sedimentary iron formations in other regions, consisting of cherts and jasperoids interbedded with ferruginous shales and sandstones. Analyses presented by Davis show the content of ferric oxide in cherts to range from 1.3 to 2.8 per cent. and in the associated shales to range from 4.9 to 15.6 per cent.

The origin of the cherts and associated rocks has been much discussed. Lawson[32] concluded that the cherts were precipitated from submarine siliceous springs, and Davis found that during all Franciscan times there were eruptions of basic igneous rocks of peculiar type, and he concludes that the hypothesis which attributes the cherts to the solutions coming from ellipsoidal basalts and the hypothesis of submarine siliceous springs were mutually interdependent. On this combination of hypothesis it would not be necessary that there be extensive lavas in immediate association with the chert. He believes that if there were magma reservoirs beneath the surface, slowly cooling, they would give rise to siliceous springs, and the existence of igneous rocks erupted at various times during the Franciscan period is proof of the existence of subterranean reservoirs of molten magma.

It would appear then, that preceding the great Pacific coast revolution there was a restricted period or periods in which si-

[30] Davis, E. F.: The Radiolarian Chert of the Franciscian Group. Univ. of Calif. Pub., Bull. Dept. of Geol., vol. 11, pp. 235–432, 1918.

[31] Davis, E. F.: The Franciscan Sandstone. Univ. of Calif. Pub., Bull. Dept. of Geol., vol. 11, pp. 1–44, 1918.

[32] Lawson, A. C.: U. S. Geol. Surv., 15th Ann. Rept., pp. 401–476, 1895.

liceous iron bearing solutions were emitted and formed extensive iron formations, though these were not originally sufficiently rich in iron and have not in many places been sufficiently enriched to form large commercial deposits. The similarity between the iron formation of the Lake Superior region and the radiolarian cherts and associated ferruginous shale of the Franciscan series of the coast has been recognized and noted by those who have studied them. It seems to be generally accepted that both are closely associated in origin with basic lavas and both have been attributed by some to submarine siliceous hot springs, as have similar formations of Wyoming.

Associated with the great coast range Sierra Nevada batholiths and allied intrusive bodies are extensive sulphide deposits valuable for gold, copper, zinc and lead. The gold deposits, as those of the Mother Lode, Grass Valley, and others, have been very productive, and the erosion of other gold deposits yielded the very productive auriferous gravel deposits of California.

The copper, copper-zinc and zinc-lead-silver deposits of northern California and western Nevada are assigned to this period, as are the deposits of base metals and silver of Idaho and adjacent areas of British Columbia.

Mineralization, like igneous activity, continued through Tertiary time. Ferguson [33] recognizes distinct periods for Nevada. The deposits associated with decreasing igneous activity following the Sierra Nevada batholithic intrusion include the Tertiary gold deposits of Nevada, such as Comstock, Goldfield and Tonopah; similar deposits of Idaho and the quicksilver deposits in the coast range of California, Nevada, Idaho and elsewhere.

The sequence of events along the Pacific Coast, therefore, seems to follow the same cycle as did the earlier periods on the opposite side of the continent, *i.e.*, (1) extensive sedimentation in geosynclines adjacent to persistent positive areas, (2) the early manifestations of igneous activity in basic lavas accompanied by iron formation probably due to siliceous and ferruginous hot springs, (3) the culmination of the cycle expressed by the intru-

[33] Ferguson, Henry G.: The Mining Districts of Nevada. ECON. GEOL., vol. 24, pp. 115–148, 1929.

sion of great batholithic bodies that crystallized as granitic rocks and were accompanied by sulphide deposits, and the decline of igneous activity with associated mineralization valuable chiefly for precious metals and quicksilver.

Rocky Mountain Cycle.

If the events that culminated in the Laramide revolution of the Rocky Mountain region are regarded as a cycle it seems to have a shorter period or a lack of some of the early expressions of igneous activity. There were, to be sure, extensive extrusions of volcanic material preceding the intrusions, but the extrusions did not begin as early nor continue as long as in the coast region. Moreover, there is no conspicuous sedimentary silica-iron formation associated with the early igneous activity. The intrusion of batholiths was on a much smaller scale and is largely concentrated about positive areas, such as the Colorado and Columbia plateaus. Associated with the intrusions, however, is very extensive mineralization including most of the copper deposits of Arizona, Utah, New Mexico, and Montana, the lead-zinc silver deposits of Utah and Colorado, and the molybdenum deposits of Colorado. With the declining stages of igneous activity following the Laramide intrusions are associated epithermal precious metal deposits, as the Marysvale deposits of Utah, the Oatman deposits of Arizona, the Mogollon deposits of New Mexico and the Cripple Creek and part of the San Juan deposits of Colorado. Where the Sierra Nevada and Laramide influences are brought close together, as in Montana and Idaho, they are hard to separate and indeed may be one. For Nevada, Ferguson makes the separation in eastern Nevada.

As has been suggested for the Keweenawan series, the lack of iron formations associated with extensive flows of the Rocky Mountain cycle may be due to their being poured out on land rather than on a sea bottom.

The Rocky Mountain cycle culminating in the Laramide revolution has been regarded by Lindgren [34] as a part of or a late phase

[34] Lindgren, W.: Differentiation and Ore Deposition in the Cordilleran Region of the United States. Ore Deposits of the Cordilleran Region, Am. Inst. of Min. Eng., Lindgren Volume (in press).

of the Pacific cycle, with which it is clearly closely associated whether regarded as separate or not.

COMPARISON OF PACIFIC AND ATLANTIC BELTS.

If so regarded, the Cordilleran region may be compared with the Appalachian, as indicated by Keith. The batholithic zone of the Appalachian would correspond to the Sierra Nevada-Central Idaho and Coast Range batholiths. The outlying dome and basin areas west of the Appalachian belt, such as the Ozark Uplift and associated basins, may correspond to the Colorado plateau area and associated negative basins.

The igneous activity around the Colorado plateau has been strong as compared with that of the Ozark region, for example, but in both, igneous activity is present around an old positive area and mineralization is extensive. It may also be noted that erosion has been less in these outlying areas than along the coastal intrusive zones. This is indicated by both the type of intrusive bodies and the character of the ore deposits associated with them. In the batholithic zone of the Appalachian region there are deep seated types of deposits, such as the pyritic copper deposits, which give place to the westward to zinc-lead deposits and to the fluorite and barite deposits. Likewise the deposits associated with the Sierra Nevada batholiths are of deep seated type, as the Mother Lode gold deposits and the northern California copper deposits, which to the eastward give place to the less deep-seated types of copper and lead-zinc deposits of Nevada, Utah, and Colorado, and to the silver and gold deposits of Colorado, such as the San Juan and the Cripple Creek deposits. Lindgren [35] has shown that fluorite becomes an important constituent in the eastern Cordilleran belt, as it does in the outlying part of the Appalachian belt.

For the Cordilleran region such an eastward change can apply only in a very general way, since, as already noted, igneous ac-

[35] Lindgren, W.: Lindgren Volume, Amer. Inst. Min. & Met. Eng., 1933 (in press).

tivity and mineralization continued in both the West Coast and Rocky Mountain areas long after the major period of intrusion, with corresponding types of deposits in each.

FIG. 6. Divisions of Tertiary (Laramide) deformation. After Keith.

CHARACTER OF MINERALIZATION AT DIFFERENT STAGES IN THE GEOLOGIC CYCLE.

From the preceding review of the ore deposits of the United States it seems that the mineralization associated with the igneous activity of the geological cycles is distinctly different at different stages. The mineralization associated with the earlier stages of igneous activity is characteristically iron formations in which the iron is predominately combined with oxygen as silicates, oxides, and carbonates, and to a small extent with sulphur as sulphides. In the later stages, associated with the stocks, iron is also abundant and in the early high temperature deposits much iron is deposited in oxygen combination as silicates, oxides and carbonate, but in the later stages much iron is deposited as sulphide, and the other metals are mainly deposited as sulphides, while metallic oxides and silicate are of relatively little importance.

It may be asked, why is there this difference? I am not able to give the answer, and to present the discussion that might lead toward an answer, I would have to go beyond the intended scope of this paper. It may be pointed out, however, that the difference is one of degree rather than of kind. The early stage represents iron deposition in oxygen combination on a grand scale, and the deposition of iron and other metals as sulphides is subordinate. Contrasted with this is mineralization associated with stocks, where iron in oxygen combination, though large, is relatively unimportant, but deposition of iron and other metals as sulphide occurs on a grand scale. The early stage of the mineralization associated with stocks, whether it takes the form of early iron vein minerals, as replacement of limestone in the form of contact deposits or as jasperoidal replacement of siliceous rocks, is essentially addition of silica and iron in varying proportions with a resultant rock chemically similar to sedimentary iron formation. Ordinarily, the iron is not sufficiently high and in sufficient quantity to form ore, and only rarely has there been enrichment of such siliceous iron deposits by later processes on a large scale. Locally the iron is sufficiently concentrated as magnetite and hematite to form small deposits of high grade. The following

table gives an idea of similarity of the mineralizing solutions that have formed sedimentary iron formation, contact deposits and silicification of lavas.

	Sedimentary Iron Formation	Limestone Garnetized		Andesite Silicified	Sedimentary Franciscan Chert	Andesite Silicified	
	1	2		3	4	5	
Hematite	26.30	Fe_2O_3	31.41	31.49	2.82	0.77	Fe_2O_3
Limonite	12.22	FeO	0.30	2.49	——	2.27	FeO
Quartz	58.07	SiO_2	32.43	61.28	95.08	95.18	SiO_2
Kaolin	1.37						
Misc.	2.04	Al_2O_3	1.53	2.42	2.17	1.20	Al_2O_3

1. Average analyses of ferruginous cherts. Van Hise, C. R., and Leith, C. K. Mesabi Dist., Minn. U. S. Geol. Surv. Mon. No. 52, p. 183.
2. Garnetized limestone. Lindgren, W. Morenci Dist., Ariz. U. S. Geol. Surv. Prof. Paper No. 42, p. 134.
3. Altered andesite, black jasper containing hematite. Rowley drainage tunnel. Burbank, W. S. Bonanza district, Colorado. U. S. Geol. Surv. Prof. Paper 169.
4. Siliceous red Franciscan chert from Red Rock Island, Calif. Davis, E. F. The Radiolarian cherts of the Franciscan group, Univ. of Calif. Publ. Geol., Vol. II, p. 268, 1918.
5. Silicified andesite. Burbank, W. S. Bonanza district, Colorado. U. S. Geol. Surv. Prof. Paper 169, p. 78.

Analyses 1 and 4 represent sedimentary iron formation, 2 garnetized limestone, and 3 and 5 silicified lavas. All were evidently formed by solutions rich in silica and with varying amounts of iron.

SUMMARY.

The ore deposits of the United States may be referred in time of formation to a few geologic cycles. The formation of ores was quantitatively a minor feature that occurred at rather definite places in the sequence. During weathering and erosion iron, manganese, aluminum and other ores and minerals were concentrated as lateritic deposits. Gold, tungsten, and some other minerals were mechanically concentrated in the sedimentary material during the process of transportation and deposition. Most deposits of these types that probably formed in the early cycles were

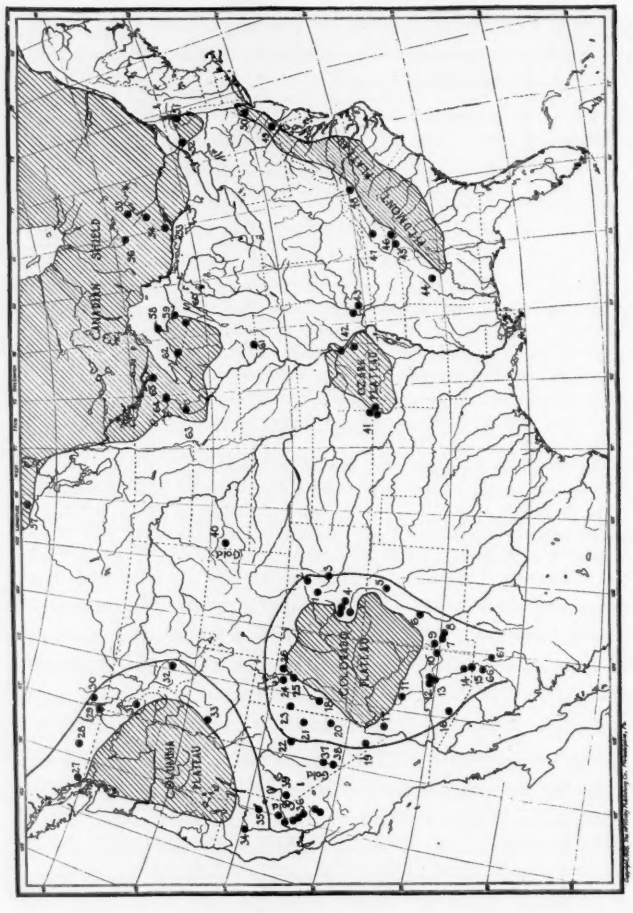


FIG. 7. Relation of mineralized districts to positive areas. For index to districts see p. 327.

later destroyed. Numerous materials were concentrated in the sea as chemical or biochemical precipitates and these were largely preserved. Concentration also occurred during the portion of the cycle when igneous forces were active. This concentration was in two main periods. An early period characterized by basic lava flows, with accompanying emanations rich in silica and iron that were deposited probably in shallow bodies of water as iron formation. This iron formation in places was sufficiently rich to form ore, but elsewhere the ore has resulted from a further process of concentration. Later in the igneous cycle, when the batholithic masses had approached the surface, there was extensive mineralization in which numerous metals were deposited mainly as sulphides and allied minerals. These two periods, however, differ more in the quantity of the different deposits than in kind. The early basic period, with its great deposits of iron in oxygen combination, has some sulphides, and the later granitic period, with the great sulphide deposits associated with the batholiths, has iron in oxygen combination as its early phase.

Two cycles are recognized in pre-Cambrian time. In post-Cambrian time the Appalachian cycle extended through the Paleozoic period and culminated in the Permian.

FIG. 7. Relation of mineralized districts to positive areas. 1. Leadville, Climax, Red Cliff, Aspen. 2. Breckenridge, Georgetown, Idaho Springs, Central City. 3. Cripple Creek. 4. San Juan. 5. Pecos. 6. Magdalena. 7. Silver City. 8. Santa Rita-Hanover. 9. Mogollon. 10. Morenci. 11. Jerome. 12. Globe, Miami, Superior. 13. Ray. 14. Tombstone. 15. Bisbee. 16. Ajo. 17. Kingman, Oatman. 18. San Francisco. 19. Goodsprings. 20. Pioche. 21. Ely. 22. Eureka. 23. Gold Hill. 24. Bingham, Ophir, Mercur. 25. Tintic. 26. Park City, Cottonwood. 27. Vancouver. 28. Kamloops. 29. Nelson. 30. Fort Steele. 31. Coeur D'Alene. 32. Butte. 33. Boise Region. 34. Shasta County. 35. Engels-Spring Garden. 36. Grass Valley, Mother Lode. 37. Tonopah. 38. Goldfield. 39. Comstock. 40. Whitewood. 41. Tri State. 42. S.E. Missouri Lead and Barite. 43. Kentucky-Illinois Fluorspar. 44. Birmingham. 45. Ducktown. 46. Swain. 47. Knoxville. 48. Austenville. 49. S.E. Penn. 50. Franklin Furnace. 51. Adirondack. 52. Edwards. 53. Sudbury. 54. Cobalt. 55. Noranda. 56. Porcupine. 57. Flin Flon. 58. Calumet. 59. Marquette. 60. Menominee. 61. Platteville. 62. Gogebic. 63. Cuyuna. 64. Mesabi. 65. Vermillion. 66. Cananea. 67. Nacozari.

FIG. 7. Relation of mineralized districts to positive areas. For index to districts see p. 327.

The Cordilleran cycle on the west coast extended through most, at least, of the Paleozoic, the Mesozoic and the Tertiary. On the coast it reached its culmination in the Post Jurassic revolution, and in the Rocky Mountain region in the Laramide revolution.

The major structural features and the igneous activity were controlled by the basins of deposition bordering the positive areas. Since the ore deposits are related to igneous activity they also border the positive areas. Such areas are the Canadian Shield with the great ore deposits on and near its margin; the Piedmont plateau of the Atlantic coast with the deposits along its western margin; the Ozark plateau with its circle of mineral districts, and the Colorado and Columbia plateaus, around which are grouped many of the great mineral districts of the western United States.

ACKNOWLEDGMENTS.

I wish to express my appreciation of criticisms and suggestions during the preparation of this paper, by my colleagues of the U. S. Geological Survey and the University of Arizona.

UNIVERSITY OF ARIZONA,
TUCSON, ARIZONA.

THE LODE DEPOSITS IN THE BOISE BASIN, IDAHO.

CLYDE P. ROSS.[1]

CONTENTS.

	Page
Introduction	329
Geologic summary	330
Kinds of lodes	333
Lodes related to the Idaho batholith	334
Tertiary lodes	336
Structure	336
Wall rock alteration	338
Vein minerals	339
Supergene processes	341
Future of the area	342

INTRODUCTION.

THE Boise Basin, Boise County, Idaho, is only a short distance northeast of the State capital. It was one of the earliest and most productive of the famous placer mining districts of Idaho. Although placer mining has declined, the activity in the lode mines has been increasing in recent years and the outlook for continued expansion is good.

The writer, assisted by S. S. Philbrick, spent 16 days in the district in the summer of 1930 for the United States Geological Survey in coöperation with the Idaho Bureau of Mines and Geology. The present paper summarizes the characteristics of the lodes of the district, particularly those in active development at the time of visit, all of which are in the northwestern part of the basin. The official report, now in preparation, will include a geologic and topographic sketch map of a small area near Quartzburg containing some of the principal mines, and maps and descriptions of nine mines, including all in operation at the time of

[1] Published with the permission of the Director, U. S. Geological Survey, and of the Secretary, Idaho Bureau of Mines and Geology.

visit. Although many details must necessarily be left until this report is published, it seems desirable at the present time to point out some features of a district that owes its comparative obscurity in part to inadequate concepts of its geology.

GEOLOGIC SUMMARY.

The Boise Basin occupies about 300 square miles. It is underlain throughout by the Idaho batholith (mainly quartz monzonite). The granitic rock is cut locally by closely related aplite, lamprophyre, and pegmatite dikes, also by much younger porphyritic dikes. This distinction in the age of the dikes has not heretofore been made in the Boise Basin, but is in accord with recent work in the surrounding region. It has a fundamental bearing on consideration of the ore deposits.

The younger dikes are mostly concentrated in the so-called "porphyry belt," which also contains most of the active gold mines. This belt extends from near Lowman on the South Fork of the Payette River southwestward across the northwestern part of the Boise Basin, and is probably essentially continuous with a similar belt near Pearl, in Gem County. The principal mines in the belt within the Boise Basin lie in an area of about 25 square miles which extends from sec. 12, T. 8 N., R. 5 E. to sec. 19, T. 7 N., R. 4 E., Boise Meridian. Many, although not all, of these lodes are genetically related to the younger dikes.

The "porphyry belt" has been studied in detail only in the vicinity of Quartzburg. The writer's mapping here demonstrates that the belt is an entity, although the dikes are neither as numerous nor individually as large as some descriptions would indicate. The dike rocks in the small area studied, fairly representative of the younger dikes throughout the belt, include dacite porphyry (intruded early in the sequence), rhyolite, granophyre and granite porphyry (closely related in character and age), and several diabasic rocks (of which some, at least, are of relatively late origin). All except the last named of these form locally the wall rock of lodes. In addition there are isolated dikes of diorite porphyry whose relations to other dikes and to the

lodes were not determined. Except for a few pegmatitic stringers, no dikes with the characteristics of those allied to the Idaho batholith are known in the vicinity of Quartzburg. They exist locally in the "porphyry belt" but appear not to be abundant anywhere within it.

The concept that the porphyritic dikes characteristic of the "porphyry belt" and consequently the lodes associated with them are of Tertiary, probably Miocene, age is based largely on (1) the close accord between the dikes and fissures structurally discordant with the Idaho batholith and corresponding closely to fissures elsewhere of known Tertiary age; (2) the petrographic dissimilarity between the majority of the dikes and any known to be related to the Idaho batholith; (3) the close petrographic resemblance between many of the dikes and distinctive rocks elsewhere in Idaho which are known to be of Tertiary (probably Miocene) age. These points will be more fully discussed in the official report which is in preparation. For present purposes it may suffice to say that much evidence is now available throughout south-central Idaho of the existence of a conjugate system of shearing which affects the Challis volcanics[2] (Oligocene or Miocene) and that dikes closely allied in character to those near Quartzburg are associated with the shearing and intrude the Challis volcanics. The shear zone followed by the dikes of the "porphyry belt" in the Boise Basin accords in trend with the major set belonging to the Tertiary system, and is on the strike of the axis of one of the major known structural disturbances affecting the Challis volcanics.[3]

In addition to the "porphyry belt" there are reported to be dike zones both north and south of Idaho City in the eastern part

[2] Ross, C. P.: Geology and Ore Deposits of the Seafoam, Alder Creek, Little Smoky, and Willow Creek Mining Districts, Custer and Gamas Counties, Idaho. Idaho Bur. Mines and Geology, Pamph. 33, p. 2, March, 1930.

[3] Anderson, A. L.: Geology and ore deposits of the Lava Creek district, Idaho. Idaho Bur. Mines and Geology, Pamph. 32, p. 26, August, 1929. Umpleby, J. B., Westgate, L. G., and Ross, C. P.: Geology and Ore Deposits of the Wood River Region, Idaho. U. S. Geol. Survey Bull. 814, p. 73, 1930. Ross, C. P.: Geology and Ore Deposits of the Casto Quadrangle, Idaho. U. S. Geol. Survey Bull. (in preparation); A Geologic Reconnaissance in the Eastern Division, Idaho Nat. Forest, Idaho and Valley Counties, Idaho. U. S. Geol. Survey Bull. (in preparation).

of the basin. These were not studied during the present investigation, but published descriptions [4] indicate that the majority of the dikes therein are aplitic and lamprophyric and hence to be correlated with the Idaho batholith rather than with the younger dikes. In and near these younger dike zones there are a number of lode mines, in many of which the mineralization appears to be so closely related to the older dikes as to be of similar age. It appears that the dikes here are less numerous and smaller and that the zones are much less clearly defined than the "porphyry belt" previously described, but as yet no detailed mapping has been done in them.

In several places in the central part of the basin, notably near Idaho City, there are limited exposures of somewhat consolidated clay, sand, and gravel. These beds are commonly appreciably tilted and locally have been faulted. They are supposed to postdate the lodes, but the majority are fine-grained and were evidently not deposited under conditions favorable to the accumulation of placer gold. Some of the gravel in them has been mined to a limited extent.[5] The scanty available data [6] indicate that these beds are probably of upper Miocene age. Small remnants of lava flows, mainly basalt, remain locally in the basin and along its northwest rim. These are commonly assumed to be of similar age to the sediments just mentioned, although evidence on this point is inconclusive. Other materially younger basalt flows fill the lower canyon of Moore Creek and have been trenched by the present stream, which is the master stream draining the Boise Basin. Auriferous ground underlies some of these younger flows.[7]

There are extensive unconsolidated and relatively undisturbed gravel and sand deposits, the oldest of which are in part inde-

[4] Lindgren, Waldemar: Mining Districts of the Idaho Basin and the Boise Ridge, Idaho. U. S. Geol. Survey, 18th Ann. Rept., pt. 3, pp. 651–680, 1898. Ballard, S. M.: Geology and Gold Resources of Boise Basin, Boise County, Idaho. Idaho Bur. Mines and Geology, Bull. 9, pp. 20–24, 1924.

[5] Lindgren, Waldemar: *op. cit.*, p. 668.

[6] Lindgren, Waldemar: *op. cit.*, p. 666. Kirkham, V. R. D.: Revision of the Payette and Idaho Formations. Jour. Geol., vol. 39, No. 3, pp. 232–235, 1931.

[7] Lindgren, Waldemar: *op. cit.*, p. 659.

pendent of present drainage and may have been laid down soon after the Miocene (?) sedimentary beds; the youngest are the products of the present streams. Deposits intermediate in age between these two extremes are locally recognizable. All these unconsolidated deposits have yielded gold in commercial quantity. Although the rich and readily accessible placers that made the district famous in the sixties have long since been largely exhausted, placer mining still continues intermittently, mainly by dredging in recent years.

The placers derived their gold from the lodes within the Boise Basin [8] at a time when the rocks and lodes were deeply weathered and the streams were overloaded. Physiographic conditions have changed so that erosion is now dominant over weathering and the accumulation of detritus.

KINDS OF LODES.

The lodes of the Boise Basin belong to two general groups: (1) those which appear to be related to the Idaho batholith; (2) those which cut the Miocene (?) dikes and hence are much younger than the batholith. The first group corresponds in age to most of the productive lodes in Idaho,[9] but in this district has not been highly productive and includes few of the mines recently active. It may be subdivided into (1) lodes characterized by coarse-grained white quartz in quartz monzonite with little or no apparent relation to dikes; (2) lodes with sparse, mainly pyritic, mineralization in shear zones associated with aplite and lamprophyre; (3) lodes structurally similar to that last mentioned but containing ruby silver. The Tertiary group of lodes includes (1) veins confined within more or less continuous walls; and (2) less definitely bounded masses in which ore deposition is largely controlled by minor partings in previously altered rock. Of these, the first includes the majority of the known Tertiary lodes but the second, although recognized at only one place (the Gold Hill mine), has proved highly productive.

[8] Lindgren, Waldemar: *op. cit.*, p. 697.

[9] Ross, C. P.: A Classification of the Lode Deposits of South-central Idaho. Econ. Geol., vol. 26, No. 2, pp. 169–185, 1931.

LODES RELATED TO THE IDAHO BATHOLITH.

Prospecting in the lodes characterized by coarse quartz and not directly associated with dikes has not been encouraging and consequently none of these lodes has as yet received much development. Some, like the Blue Rock prospect on upper Confederate Gulch, are guided by the locally most prominent joints in the quartz monzonite. Others, according to Ballard,[10] are longer and may be related to regional shearing independent of and older than that of the "porphyry belt." Sulphides are irregularly distributed in bunches through the quartz of these veins. At the Blue Rock and a neighboring prospect they include pyrite, sphalerite, galena, tetrahedrite, and chalcopyrite. The wall rocks are less altered than in most of the lodes of the district. Ballard reports that several such veins locally contain pegmatite, a fact that links these veins with molybdenite deposits in the vicinity of Rocky Bar, Elmore County,[11] which are closely related to pegmatite of Idaho batholith age. Most of the molybdenite deposits contain pyrite with which considerable gold and silver are associated. Ballard notes that in veins of this kind in the Boise Basin some of the pyrite was deposited in shear zones of later origin. He also says that the few ore shoots known in them are near basic dikes that cut the vein quartz.

Most of the pyritic lodes on shear zones associated with aplite and related rocks, and hence inferred to be of Idaho batholith age, are in the eastern and southeastern parts of the Boise Basin. Although they include a number of those best known in the early days, none of them has received much attention recently. The following account is summarized from descriptions by Lindgren [12] and Ballard.[13]

Many of the veins which appear to be of this kind strike northwest, although some have other trends. Shearing and alteration of the granitic wall rock is more pronounced than in the lodes

[10] Ballard, S. M.: *op. cit.*, pp. 39–40.

[11] Schrader, F. C.: Molybdenite in the Rocky Bar District, Idaho. U. S. Geol. Survey Bull. 750, pp. 92–93, 1925.

[12] Lindgren, Waldemar: *op. cit.*, pp. 684–689.

[13] Ballard, S. M.: *op. cit.*, pp. 40–41, 95–99.

just described. Aplite is common in and near the lodes and in several places dikes of this rock lie in and parallel to the mineralized shear zones and are themselves fractured and somewhat mineralized. In addition there are more basic dikes, the majority of which appear to be minette. Where the relationship has been determined these are older than the mineralization. Some of the ore mined for gold in the early days contained little or no visible sulphide. Pyrite, arsenopyrite, sphalerite, galena, and stibnite are locally present, the first being evidently the most widespread and abundant. Quartz is the most abundant gangue mineral but calcite is locally present.

The Comeback lode, discovered in 1924, a short distance north of Pioneerville, is the only one in the Boise Basin known to be characterized by the presence of ruby silver (pyrargyrite). Similar lodes have, however, long been known in the Banner district a short distance northeast of the border of the basin.[14]

The country rock belongs to the Idaho batholith, although somewhat more silicic than most of the granitic rock of the Boise Basin. Within the principal shear zone there is a lamprophyre dike that has been altered and pyritized but nowhere has been found to contain ore. At one place in the workings, dacite porphyry (Miocene?) is exposed. This rock appears to have caused a pinch in the ore body and is itself strikingly fresh. Hence it is doubtless later than the mineralization. Although the Comeback lode is within the "porphyry belt" and strikes northeast, like many of the Tertiary lodes of that belt, its relation to the dacite porphyry distinguishes it from these lodes. The marked difference in the character of the mineralization strengthens this conclusion.

At least two mineralized shear zones are present but most of the development has been confined to one of them. When visited in 1930 much of the material being mined was rather massive, rudely banded sulphide ore, consisting mainly of pyrite, galena, and sphalerite with specks of chalcopyrite in a gangue of coarsely

[14] Lindgren, Waldemar: *op. cit.*, p. 695. The Gold and Silver Veins of Silver City, De Lamar, and Other Mining Districts in Idaho. U. S. Geol. Survey, 20th Ann. Rept., pt. 3, p. 104, 1900.

crystalline quartz. The pyrite is in crystals and far less shattered than is common in the Tertiary lodes. Locally the ore contains pyrargyrite and arsenopyrite. Shipments so far had been confined to ore from high-grade pockets reported to average over $200 a ton, mainly in gold, with some small shipments materially richer. There is in the mine, however, a considerable amount of lower grade material which, in the absence of a mill, was being left unmined.

TERTIARY LODES.

Structure.—All the lodes recognized as Tertiary are in the "porphyry belt" in the northwestern part of the Boise Basin. Nearly all are definitely later than the silicic porphyry dikes. Where relations have been established, the diabasic dikes are later than the mineralization. In a few cases, such as the Missouri mine, the relation between the porphyry dikes and the lodes could not be determined from the exposures seen during the recent study, but the character of the ore and structural relations suggest correlation with the Tertiary lodes.

Most of the lodes lie within limited fissure zones with more or less well defined walls which are products of a renewal of earth movement along the "porphyry belt" shortly after the intrusion of the porphyry dikes. The major fractures of this period trend N. 70°–80° E. The dip is commonly steep to the south but locally flattens to as little as 30°. Although these fractures (and hence the lodes that occupy them) closely parallel the average trend of the principal dikes, there is much discordance in detail. Considerable stretches of the mineralized fissures are in the granitic rock of the Idaho batholith and much of the ore is in these portions of the lodes. The Gold Hill vein at Quartzburg, (Fig. 1) the largest single producer among the lodes worked in the early days, was on a fissure belonging to this set. Little work has been done on this vein since about 1900, most of the known ore having been mined. The ore shoot here varied in width up to 6 feet, had a maximum stope length of about 3,500 feet, and was followed through a vertical range of about 800 feet. Numerous other lodes with similar trends are known, among

which the Belshazzar and Mountain Chief, 3½ and 4 miles respectively west of Placerville, are still being actively developed and the former, especially, has yielded much good ore.

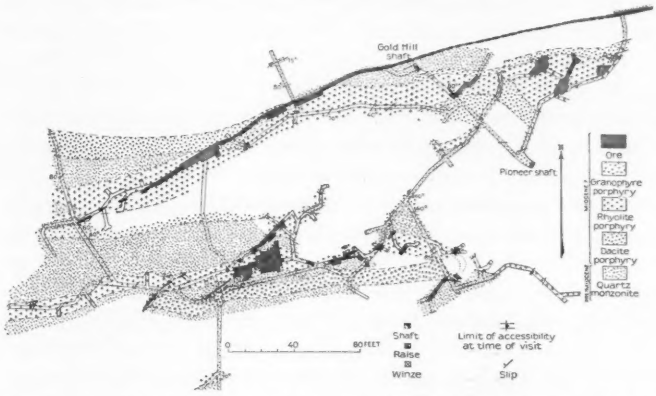


FIG. 1. Geologic map of the 250 level, Gold Hill Mine, Quartzburg, Idaho. Base from the company's maps. Geology by Clyde P. Ross, in part after A. J. McDermid. June, 1930.

In addition to the fissures above referred to there is a subordinate set of somewhat more irregular and variable trend. Most of the stronger fissures of this set have trends between N. 30° E. and N. 60° E., with the majority of the more persistent ones averaging near N. 35° E. Some of these fissures dip northwest but the majority dip southeast, commonly at angles of 75° to 90°. Many of the fissures of this set are short and show little or no mineralization. The veins in such mines as the Mayflower, half a mile southwest of Quartzburg are on fissures belonging to this set.

A structurally different kind of lode is represented by the ore bodies in the Pioneer workings of the Gold Hill mine. These comprise a number of isolated deposits in the hanging-wall of the Gold Hill vein, developed mainly since that vein was abandoned. They have no appreciable surface expression and were found only by underground exploration. This inconspicuousness

leads to the hope that equally valuable similar deposits may lie undetected in the vicinity of some of the other veins. Some of the ore bodies in the Pioneer workings are nearly parallel to and possess some of the characteristics of the Gold Hill vein, but the majority trend N. 30°–60° E. and the stoping ground is limited by decrease in assay value rather than by definite walls. These ore bodies are controlled in general trend by fissures of the second or subordinate set mentioned above. Such fissures are commonly visible in the stopes but are discontinuous and do not confine the mineralization. Ore has been found in the granitic rock and also in the successively younger dikes of dacite porphyry, rhyolite porphyry, and granophyre porphyry. The rhyolite porphyry, however has proved much the more favorable host rock for ore bodies of the kind here discussed. Wherever mineralization in these deposits has been followed from rhyolite porphyry into the other rocks it has decreased promptly in dimension and grade. Some sulphides are disseminated through the altered country rock, but in the valuable ore bodies a large proportion of the metallic minerals is deposited along individually small jagged seams rather closely spaced, and lying at acute angles to the larger slips that govern the trend of the ore body. It appears that the rhyolite porphyry was especially susceptible to the general sericitic alteration which was an early step in the process of mineralization. The greater mechanical weakness thus produced permitted this rock to be more readily broken by subsequent readjustments so that the minor seams, which formed passageways for the metallic minerals formed comparatively late in the sequence, are more numerous and closely spaced in this rock than in the others with the result that, as noted, most of the ore is confined to it.

No single ore body in the Pioneer workings has proved to be as large as that mined in the Gold Hill vein, but many are of considerable size. They are commonly 20 feet or more in width and have stope lengths ranging to more than 100 feet and vertical dimensions ranging up to 500 feet.

Wall Rock Alteration.—All the rocks in the vicinity of Tertiary lodes are altered; the basic dikes least and the rhyolite porphyry most. Increase in alteration has been found by experience

to indicate approach to an ore body, especially in the Pioneer workings. Wall rock alteration is a more conspicuous feature here than in any of the other mines visited, although the character of the alteration around all the Tertiary lodes is similar. It consists mainly in sericitization of the feldspar and bleaching and decomposition of the mica. Calcite is widely but rather sparsely developed. Pyrite crystals are sparsely disseminated through the altered rock, especially in and near the ore bodies. Exceptionally a little tremolite has formed in the altered rock.

Vein Minerals.—The known hypogene metallic minerals in the Tertiary lodes include pyrite, galenobismutite and related minerals, arsenopyrite, native gold, sphalerite, galena, tetradymite, pyrrhotite, stibnite, chalcopyrite, and either tetrahedrite or tennantite. Of these, the first four are the only ones conspicuously abundant in mines visited during the present investigation.

Pyrite is the most universally present of these minerals. It is rather sparsely disseminated through the country rock and in the vein quartz. There are occasional seams filled almost exclusively with pyrite. In a few places it has crystallized in cubes up to half an inch or more in width. Much of the pyrite was formed early in the sequence of mineralization, probably in part in connection with the sericitization of the host rock. In many places it has been shattered and the interstices filled with galena, sphalerite, and other minerals. Assays show that the pyrite is auriferous but not high-grade.

Ballard,[15] as a result of studies made in 1922 or 1923 by the Idaho Bureau of Mines and Geology showed that the dark gray sulphide, plentiful in much of the ore in lodes in the general vicinity of Quartzburg, is a bismuth mineral instead of stibnite as had formerly been supposed. Shannon [16] had previously shown that the gray material in a specimen of typical ore from the Belshazzar mine analysed by him was galenobismutite ($PbS.Bi_2S_3$). The parts of the Belshazzar lode accessible in 1930 contained

[15] Ballard, S. M.: *op. cit.*, pp. 35–36.

[16] Shannon, E. V.: Or. Galenobismutite from a Gold-quartz Vein in Boise County, Idaho. Washington Acad. Sci. Jour., vol. 11, No. 13, pp. 298–300, 1921. The minerals of Idaho. U. S. Nat. Mus. Bull. 131, pp. 147–148, 1926.

little of the bismuth mineral, but similar material was abundant in the Pioneer stopes of the Gold Hill mine. Microscopic studies by M. N. Short and the writer show that this material is galenobismutite or a similar mineral. The surfaces of different grains exhibit slight color differences but the tests made indicate that all are of essentially the same composition. Ballard states that there are several sulphide minerals of bismuth in the ore bodies near Quartzburg, including bismuthinite (Bi_2S_3), beegerite ($6PbS.Bi_2S_3$), cosalite ($2Pbs.Bi_2S_3$), lillianite ($3PbS.Bi_2S_3$) and others. Although the precise character of the bismuth mineral thus remains in some doubt, it seems clearly established that it is an isomorphous mixture of the sulphides of lead and bismuth. This material probably formed late in the sequence of hypogene mineralization.

Arsenopyrite is one of the most conspicuous components of the accessible parts of the Belshazzar and Mountain Chief lodes but is absent from most others. There is a little pyrrhotite in the arsenopyrite ore.

It is clear that most of the gold in the Tertiary lodes is in the native state and that, in present workings, it is a hypogene constituent intimately associated with the sulphide minerals. The gold content of the ore increases with increase in the sulphides, especially galenobismutite and pyrite. However, the fact that simple amalgamation recovers over 95 per cent of the gold in the Pioneer ore and over 70 per cent of that from the Belshazzar mine demonstrates that most of this metal is not chemically combined in the sulphides. Much of the gold is so fine grained as to be difficult to detect, even microscopically, but the richer ore invariably contains flakes visible to the unaided eye, and microscopic examination of a number of such specimens, both by the Idaho Bureau of Mines and Geology for Ballard's report and by M. N. Short and the writer in connection with the present study, show the intimate, primary intergrowth of the gold with the bismuth mineral. Very coarse gold has been found in pockets between the No. 3 and 401 levels of the Belshazzar mine, well below any evidence of oxidation. Specimens from these pockets contain coarse arsenopyrite crystals projecting into open

cavities, with gold deposited on the surface of the crystals and also intricately intergrown with the arsenopyrite in the walls of the cavities. Most of the sulphide ore from the Tertiary lodes contains $8 to $15 in gold and associated silver, with occasional pockets of richer material.

The other sulphide minerals were nowhere abundant in the mines seen in 1930. Sphalerite and galena are reported to have been more plentiful in the upper workings than in the present stopes. There are some Tertiary lodes elsewhere in the district, especially near Grimes Pass, in which these sulphides are so abundant as to be of possible commercial value.[17] Some of the ore from the same part of the district locally contains considerable copper, mainly as chalcopyrite.

The gangue is mainly altered host rock and vein quartz. Many of the slips are lined with small to moderate amounts of gouge, somewhat mineralized. Some of the seams are filled with a white, clay-like material that is mainly composed of sericite. Barite is sparingly present in some lodes. Quartz is the most conspicuous of the introduced gangue minerals, especially in the more definitely vein-like lodes such as the Gold Hill, Belshazzar, and Mountain Chief. It is less prominent in the Pioneer ore bodies but is the principal mineral filling the small seams that in the aggregate constitute these deposits.

SUPERGENE PROCESSES.

The early lode miners concentrated their efforts on the accessible and easily treated oxidized ore, and its prompt exhaustion is one of the reasons why the lodes of the Boise Basin, known for over 70 years, have received so little development. Observations by the writer, coupled with published descriptions of the early work, especially those of Lindgren,[18] show that oxidation of the lodes is generally shallow and inconsequential. Sulphide remains at or close to the surface in many places. Locally there is some evidence of oxidation at depths as great as 150 feet but in most places its effects were feeble at much less depth. The

[17] Ballard, S. M.: *op. cit.*, pp. 34, 35, 47, 75–94.

[18] Lindgren, Waldemar: *op. cit.*, pp. 689–695.

easily oxidized hypogene mineral sphalerite remains unaffected in the upper levels of several mines. Evidence of supergene sulphide enrichment is meager, even in copper ore. Manganese, which facilitates the supergene transfer of gold,[19] is locally present but appears nowhere to be abundant.

The physiographic history of the region is in accord with these facts. After the lodes were formed there was a period of deep weathering and of overloaded streams, but in comparatively recent times erosion has been the dominant process. As already pointed out, the gold in most of the sulphide ore recently mined is clearly of hypogene origin. It is concluded that, although present evidence does not preclude the possibility of local supergene enrichment of gold below the oxidized zone, it is not probable that this process has been sufficiently effective to be of material commercial significance in future development. This conclusion implies that structural and other conditions independent of the depth below the present surface, are the determining factors in the persistence of sulphide ore in this region.

FUTURE OF THE AREA.

Development of the lodes of the Boise Basin has been, for the most part, sporadic, shallow, and unsystematic. A number of the deposits were abandoned after the shallow zone of oxidized, easily amalgamated ore was exhausted. According to Ballard,[20] little except assessment work was done at most mines from the time that treatment of the sulphides proved metallurgically difficult until 1920, when some of the deeper ore shoots began to be successfully developed.

The data gathered during the writer's investigation do not appear to warrant this neglect. Results of milling at the Gold Hill mine show that some, at least, of the sulphide ore, will yield exceptionally excellent recoveries to amalgamation done under proper conditions, so that there is no longer any occasion to confine development to the oxidized parts of the lodes. The Bel-

[19] Emmons, W. H.: The Enrichment of Ore Deposits. U. S. Geol. Survey Bull. 625, pp. 308–310, 318, 1917.

[20] Ballard, S. M.: *op. cit.*, p. 50.

shazzar vein has been traced through 550 feet vertically or over 1,000 feet on the dip, and the Pioneer deposits have been mined to a vertical depth of 850 feet, or 1,350 feet below the highest stopes on the adjacent Gold Hill lode. It is, therefore, logical to hope that the relatively shallow development in most other parts of the "porphyry belt" has disclosed only a fraction of the potential ore reserves. This hope applies particularly to deposits resembling those in the Pioneer workings. Outcrops of such lodes would generally be inconspicuous, and they may exist locally in the walls of some of the better defined veins without any clear superficial evidence of their presence.

In so far as the prejudice against lodes within the main Idaho batholith is founded on the belief that they represent merely the "roots" of lodes largely eroded away, it has some foundation in fact, especially as regards base metal deposits genetically related to the batholith, but this prejudice, which has probably had a tendency to retard development in the Boise Basin, does not apply to the Tertiary deposits of the "porphyry belt." These deposits, furthermore, must not be confused with Tertiary deposits formed close to the surface and generally in Tertiary lava. Although deposits of the latter type in Idaho are locally rich and have a record of enviable persistence as compared with many of those of Mesozoic age,[21] very few of them have been profitably worked through a large vertical range. The Tertiary deposits of the Boise Basin, on the other hand, are of mesothermal type,[22] formed at intermediate temperatures and at depths of some thousands of feet below the existing surface. Lodes of this type are obviously independent of the present surface. Where, as in this case, the containing rocks and governing structural conditions are such as to be persistent at depth, the lodes may well be similarly persistent.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

[21] Ross, C. P.: A Graphic History of Metal Mining in Idaho. U. S. Geol. Survey Bull. 821, p. 7, 1930.

[22] Lindgren, Waldemar: Mineral Deposits, pp. 134–136. 3d Ed., 1928.

PETROGRAPHY OF THE FULLER'S EARTH DEPOSITS, OLMSTEAD, ILLINOIS, WITH A BRIEF STUDY OF SOME NON-ILLINOIS EARTHS.[1]

RALPH E. GRIM.

INTRODUCTION.

THE term " fuller's earth " is herein applied to any clay that has a high capacity for removing color from animal, vegetable, or mineral oils. No particular composition, texture, or genesis is implied by the term, although decolorizing ability may be related to these factors. The name was derived from the original use of earth for removing grease and fat from woolen cloth during the process of fulling.

Much of the fuller's earth in continental Europe is produced by weathering of basic igneous rocks or is a sedimentary product derived from them. As a result the term fuller's earth (*Walkererde*) as used by some workers,[2] notably the Germans, has had a genetic implication. In England the term has been used also as a formation name. Elsewhere clays of a wider variety are used for bleaching and the term has had no genetic or stratigraphic significance.

Acknowledgments.—Drs. C. S. Ross and P. G. Nutting of the United States Geological Survey, the State Geologists of Florida, Georgia, Arkansas, and Texas, the Standard Oil Company of Indiana, the Sinclair Refining Corporation, and L. A. Salomon and Brother, Importers, supplied the samples of non-Illinois bleaching clays. Various colleagues on the Illinois Geological Survey staff have offered helpful discussion.

OLMSTEAD FULLER'S EARTH.

Occurrence.—At the present time all the fuller's earth produced in Illinois is mined near Olmstead, Pulaski County, in the

[1] Published with the permission of the Chief, Illinois State Geological Survey.

[2] Dammer, B., and Tietze, O.: Die Nutzbaren Mineralen, pp. 419–429, Enke, Stuttgart, 1914.

extreme southern part of the State. The deposits occur in the upper part of the Porters Creek formation of the Midway group of the Eocene system.[3] The Porters Creek formation in Illinois is composed of clay deposited in a near-shore marine environment and is fairly uniform lithologically. It occurs in a belt extending across the southern part of Illinois.[4] In a future paper it is planned to discuss in detail the sedimentation of the Porters Creek clay.

Lithology.—The fuller's earth as exposed in the pits of the Standard Oil Company of Indiana and of the Sinclair Refining Corporation consists of (1) a top, slightly sandy, light gray clay 10 to 20 feet thick; (2) a middle, very sandy gray clay about 10 feet thick; and (3) a bottom, dark gray, very sandy clay which extends below the lowest level of the pits. Only the two upper horizons are used commercially as fuller's earth. The boundaries between the horizons are irregular and gradational. The sandy content varies from about 10 per cent. in the top horizon to as much as 55 per cent. in the basal beds. The sand occurs in small lenticular aggregates scattered through the clay and as individual disseminated grains. The lenticular sandy masses are commonly stained yellow by limonitic material which is believed to have been produced by the alteration of glauconite contained in the clay. Thin beds of yellow limonitic clay are irregularly interstratified with the gray clay.

All the clay is dark brown to dark gray and sticky and slippery when wet. It is tough, breaks with a conchoidal fracture, lacks pronounced bedding, and is difficult to disaggregate in water. It is not fossiliferous except for a few microscopic cellular masses that are probably of organic origin.

Mineral Composition.

The chief constituents in the order of their abundance are montmorillonite, quartz, muscovite, glauconite, and amorphous silica. A few other minerals are extremely rare.

[3] Lamar, J. E.: Preliminary Report on the Fuller's Earth Deposits of Pulaski County. Illinois Geol. Survey, Rept. of Inves. 15, p. 10, 1928.

[4] Lamar, J. E.: *Idem*, p. 31. Lamar, J. E., and Sutton, A. H.: Cretaceous and Tertiary Sediments of Kentucky, Illinois, and Missouri. Bull. Amer. Assoc. Pet. Geol., vol. 14, pp. 845–866, 1930.

Montmorillonite.—The dominant and characteristic mineral is montmorillonite, $(Mg, Ca)O.Al_2O_3.5SiO_2.(5–8)H_2O$,[5] which was identified by its optical data, chemical analyses, dehydration curves, and X-ray data, which are similar to corresponding data furnished by type montmorillonite (Tables I–IV, Figs. 1 and 2).

TABLE I.

OPTICAL PROPERTIES OF MONTMORILLONITE.

	α	γ	$\gamma - \alpha$	$2V$	Optical Character
Olmstead, Illinois:					
Top horizon, Standard pit	1.500	1.523±.003	.023	13°±	(−)
Middle horizon, Standard pit	1.499	1.522 "	.022	small	(−)
Bottom horizon, Standard pit	1.500	1.523 "	.022	small	(−)
Top horizon, Sinclair pit	1.500	1.523 "	.022	small	(−)
Middle horizon, Sinclair pit	1.499	1.522 "	.022	13°±	(−)
Bottom horizon, Sinclair pit	1.500	1.523 "	.022	12°±	(−)
Other localities: [a]					
Otay, San Diego Co., Calif.	1.492	1.513	.021	16°–24°	(−)
Maricopa, Kern Co., Calif.	1.492	1.515	.023	15°–22°	(−)
Fort Steel, Wyo.	1.484	1.508	.024	13°–24°	(−)
Wisconsin, Tex.	1.493	1.515	.022	7°–19°	(−)
Quilchena, B. C.	1.487	1.514	.027	18°±	(−)
Rideout, Utah	1.478	1.500	.022	10°–16°	(−)
Montmorillon, France	1.503	1.527	.024		(−)
Bainbridge, Ga.	1.512	1.535	.023	17°–25°	(−)

[a] Ross, C. S., and Shannon, E. V.: *Op. cit.*, pp. 95–96.

The optical data of the Olmstead clay mineral and of montmorillonite from other localities agree within reasonable limits (Table I). The chemical analyses of the Olmstead clay mineral agree fairly well with the other analyses of montmorillonite (Table II). The variations between the Olmstead clay mineral and the type or theoretical montmorillonite are no greater than the variations between various montmorillonites, nor does the Olmstead mineral vary appreciably in different parts of the deposit. The dehydration curves of the Olmstead clay mineral (Fig. 1) are similar to those published [6] for clays that will be

[5] Ross, C. S., and Shannon, E. V.: The Minerals of Bentonite and Related Clays and their Physical Properties. Jour. Amer. Cer. Soc., vol. 9, p. 87, 1926.

[6] Nutting, P. G.: The Bleaching Earths. Ind. and Eng. Chem., Anal. Ed., vol. 4, no. 1, p. 140, 1932.

shown later to consist of montmorillonite and conform to the behavior of typical montmorillonite, which loses a large part of its water below 120° C. and the remainder gradually with rising temperature.[7] The X-ray data for the Olmstead clay mineral and montmorillonite are practically identical (Fig. 2 and Table IV), the only variations being slight differences in the spacing of a few

TABLE II.

CHEMICAL ANALYSES OF MONTMORILLONITE.[a]

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
SiO_2. . . .	60.78	58.06	56.20	61.70	55.42	58.82	54.46	56.20	48.60	51.28	50.60
Al_2O_3. . . .	13.83	15.03	15.40	13.11	15.61	15.12	16.84	13.20	20.03	10.56	17.23
Fe_2O_3. . .	4.36	4.26	4.17	2.67	3.55	3.24	3.36	5.08	1.25	6.76	
FeO. . . .	.14	.16	.16	1.96	.20	.73					
MgO. . . .	1.85	2.18	1.96	1.67	1.46	1.98	4.84	2.92	5.24	10.40	4.56
CaO. . . .	1.19	.53	.47	.85	.94	.55	3.20	1.60	1.72	1.44	3.21
Na_2O. . .	.19	.16	.15	.28	Tr	.06					
K_2O. . . .	1.16	.90	1.13	.98	1.41	1.34					
H_2O-. . .	5.18	5.13	6.30	5.36	6.35	4.65	16.10	20.32	21.52	20.28	24.32
H_2O+. . .	11.10	13.11	13.25	10.71	14.28	12.52					
TiO_2. . . .		.35	.45	.23	.46	.44	.80		MnO		
P_2O_5. . . .	.26	.44	.33	.52	.26	.37			.16		
Total. . .	100.04	100.31	99.97	100.03	99.94	99.82	99.60	99.32	98.52	100.72	100.00

I. Top horizon, Standard pit, Olmstead, Ill.;
II. Middle horizon, Standard pit, Olmstead, Ill.;
III. Bottom horizon, Standard pit, Olmstead, Ill.;
IV. Top horizon, Sinclair pit, Olmstead, Ill.;
V. Middle horizon, Sinclair pit, Olmstead, Ill.;
VI. Bottom horizon, Sinclair pit, Olmstead, Ill.;
VII. Montmorillonite from bentonite, Conejos Quad., Colo.;[b]
VIII. Montmorillonite from bentonite, Quilchena, B. C.;[b]
IX. Montmorillonite, Montmorillon, France;[b]
X. Montmorillonite from fuller's earth, Attapulgus, Ga.;[b]
XI. Montmorillonite, Theoretical composition to satisfy formula (Mg, Ca)O. $Al_2O_3 . 5SiO_2 . 8H_2O$ with MgO : CaO = 2 : 1

[a] The samples of purified mineral in the Olmstead fuller's earth that were analyzed chemically were obtained by thoroughly disintegrating the clay in distilled water, decanting the suspension, removing the clay fraction suspension by means of porcelain filter cones, and drying it at room temperature. A microscopic examination showed that the clay mineral fraction was practically free from impurities. These samples were analyzed by O. W. Rees, Associate Chemist, Illinois State Geological Survey.

[b] Ross, C. S., and Shannon, E. V.: *Op. cit.*

[7] Ross, C. A., and Shannon, E. V.: *Op. cit.*, p. 91.

of the lines. However, these variations are within the limit of accuracy for patterns as diffuse as those yielded by the group of clay minerals to which montmorillonite belongs.[8] The similarity of the patterns is further indicated by the fact that the intensities

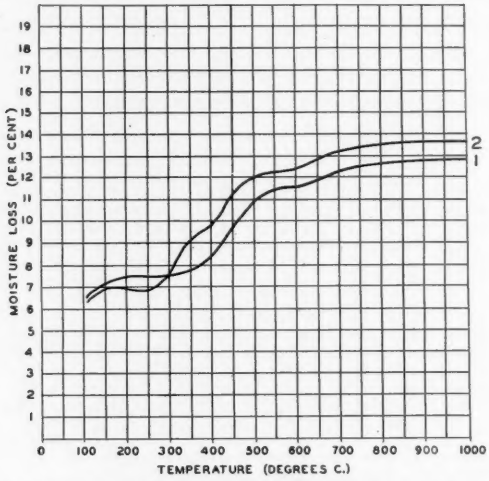


FIG. 1. Dehydration curves for purified clay mineral from Olmstead, Illinois. (See Table III.)

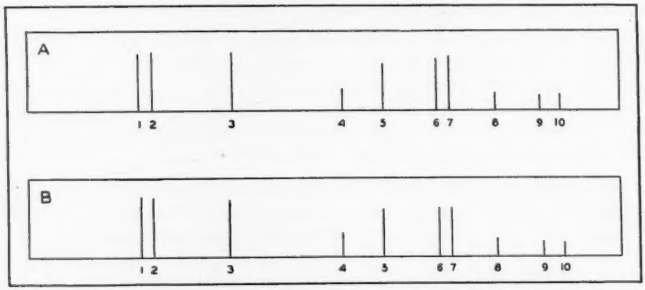


FIG. 2. Diagram illustrating the X-ray diffraction patterns of (*A*) Olmstead fuller's earth, and (*B*) montmorillonite, Montmorillon, France. (See Table IV.)

[8] Kerr, P. F.: *Op. cit.*, p. 164.

TABLE III.

DEHYDRATION OF MONTMORILLONITE FROM OLMSTEAD.[a]

[a] Determinations by O. W. Rees, Illinois Geological Survey.

Temp. ° C.	Moisture Loss in Per Cent.		Temp. ° C.	Moisture Loss in Per Cent.	
	1	2		1	2
110°.....	6.39	6.28	485°.....	10.69	11.90
160°.....	7.38	6.93	530°.....	11.25	12.27
250°.....	7.23	6.87	600°.....	11.68	12.55
300°.....	7.50	7.14	650°.....	11.97	12.88
350°.....	7.74	9.04	700°.....	12.23	13.26
375°.....	7.93	9.45	750°.....	12.49	13.53
400°.....	8.28	9.85	1000°.....	12.78	13.78
450°.....	9.78	11.42			

1. Upper horizon, Standard Oil Company pit, Olmstead, Illinois.
2. Upper horizon, Sinclair Refining Company pit, Olmstead, Illinois.

TABLE IV.

INTERPLANAR SPACING AND INTENSITY OF OLMSTEAD FULLER'S EARTH AND MONTMORILLONITE FROM MONTMORILLON, FRANCE.

Olmstead fuller's earth [a]			Montmorillonite Montmorillon, France [b]		
Line No.	Spacing in Angstrom units	Intensity	Line No.	Spacing in Angstrom units	Intensity
1	4.50	strong	1	4.49	strong
2	4.10	strong	2	4.05	strong
3	2.55	strong	3	2.48	strong
4	1.69	weak	4	1.67	weak
5	1.49	strong	5	1.47	strong
6	1.29	strong	6	1.29	strong
7	1.25	strong	7	1.25	strong
8	1.12	weak	8	1.115	weak
9	1.03	weak	9	1.020	weak
10	.97	weak	10	.976	weak

[a] X-ray analyses and calculations (identical for six purified samples) made by Dr. W. A. Sisson, University of Illinois, using a General Electric Company diffraction apparatus with Ka radiation of molybdenum according to method described by W. P. Davey, General Electric Review, vol. 25, pp. 565–580, 1922.

[b] Kerr, P. F.: Bentonite from Ventura, California. ECON. GEOL., vol. 26, pp. 164–167, 1931.

of the lines are identical. The X-ray data show no additional lines suggestive of a mixture of other clay minerals than montmorillonite. The optical data likewise indicate that the Olmstead earth contains no clay mineral other than montmorillonite. These data indicate no appreciable vertical or lateral variation in the Olmstead deposits.

In thin section, the Olmstead montmorillonite is light grayish yellow. Much of it occurs in particles too small to permit a determination of shape or size, although it appears to be entirely crystalline. The larger particles are flaky with the acute bisectrix about perpendicular to the larger surface. The flakes are mostly .005 mm. or less, occasionally .01 mm. in diameter, and about a micron thick. The larger flakes have probably increased in size since deposition. A few veinlets of montmorillonite cut across the rock. The montmorillonite in the veinlets differs from that in the balance of the rock by slight differences in the orientation of the mineral particles. These veinlets indicate that there has been some transfer of montmorillonite after the consolidation of the sediment.

Quartz.—Quartz in unsorted grains occurs in small streaks and lenses and irregularly scattered through the clay. They reach a maximum diameter of .12 mm. Those in the lenses and streaks are somewhat larger than the scattered ones. Some of the larger grains are well rounded, but most of them are distinctly angular. With very few exceptions extinction shows that the grains are unstrained. The quartz grains in the lenses fit together perfectly and are commonly cemented by silica, suggesting that since the accumulation of the sediment some of the silica in the quartz grains has been dissolved and redeposited to fill interstitial spaces (Fig. 3, *left*). Some of the quartz grains show distinct embayments of montmorillonite indicating a partial replacement of the quartz by the clay mineral (Fig. 3, *right*).

Muscovite.—Flakes of muscovite constitute 1 to 2 per cent. of the total rock mass. The flakes, many of which are frayed, are of all sizes up to a maximum of .25 mm. in diameter and .02 mm. in thickness. Many of them have been partly altered or replaced

by montmorillonite (Figs. 4 and 5). Some of the larger flakes show montmorillonite along the internal cleavage surfaces where it must have been formed in place. Many of the mica flakes grade into the surrounding montmorillonite, which commonly has the same orientation as the central mass of muscovite. Pseudomorphs of montmorillonite after muscovite also occur.

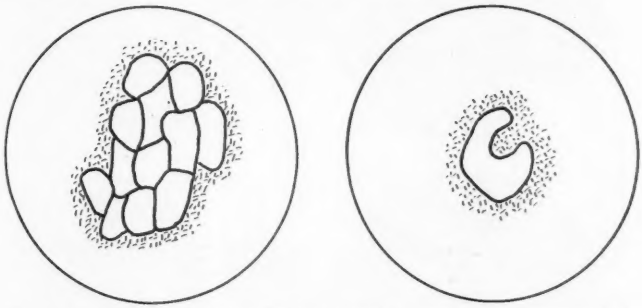


FIG. 3. (Left.) Quartz grains showing mutually accommodating boundaries surrounded by montmorillonite. (Right.) Quartz grain showing an embayment of montmorillonite.

It is not always possible to prove whether the muscovite is altering to montmorillonite or is forming from it, especially in the case of small flakes whose exact identity can not be determined, but it is believed that some of the small flakes of muscovite have formed from the montmorillonite.

Glauconite.—Glauconite, which constitutes 1 to 2 per cent of the rock mass, occurs as rounded grains and irregular masses with a maximum diameter of .1 mm., and is uniformly distributed through the deposit. It varies in color from light-green to dark-green. Two fairly distinct types with intergradations are present. One type is rounded, has a mottled appearance, and under crossed nicols it appears as an aggregate of minute crystalline particles. The other type occurs as irregularly shaped crystalline grains with a pronounced cleavage, creating a micaceous appearance. The average optical constants measured on a series of the latter type of grains from various parts of the deposit are: $2V = 16° \pm$;

m
4
m
5
6
7
8
9

(—); $\gamma - \alpha = .025$, $\gamma = 1.615$, $\alpha = 1.590$; pleochroism —Z = yellow-green, X = light yellow-green.

Some grains show alteration to brown limonite, with all gradations from slightly altered grains to limonite pseudomorphic after glauconite. Also many of the glauconite grains appear to have been altered to or replaced by montmorillonite, as suggested by gradation from the glauconite grain to the surrounding montmorillonite, by veinlets and embayments of montmorillonite cutting into and across glauconite grains, and by pseudomorphs of montmorillonite after glauconite. Montmorillonite commonly penetrates glauconite grains that have pronounced cleavage. It is not always possible to determine whether the glauconite is altering to or forming from montmorillonite but in most instances evidence for the alteration of the glauconite is clear. A few grains of glauconite show alteration to both limonite and montmorillonite, in which case the alteration to limonite occurred first, as shown by veinlets and embayments of montmorillonite in limonitic glauconite and by partial pseudomorphs of montmorillonite after limonitic glauconite (Figs. 6–9).

FIGURES 4–9. PHOTOMICROGRAPHS OF FULLER'S EARTH, FROM OLMSTEAD, ILL.

FIG. 4. Fragment of muscovite (*m*) grading and altering to montmorillonite (*c.m.*), and showing original muscovite outline. × 165.

FIG. 5. Montmorillonite (*c.m.*) advancing along cleavage planes of muscovite (*m*). × 165.

FIG. 6. Grain of glauconite (*g*) whose original boundaries are still discernible (as outlined), partly altered to or replaced by montmorillonite (*c.m.*), and quartz grains (*q*) with mutually accommodating boundaries. × 165.

FIG. 7. Micaceous glauconite (*g*) altering to montmorillonite (*c.m.*) which is penetrating along cleavage planes. × 165.

FIG. 8. Fragment of micaceous glauconite (*g*) altering to limonite (opaque) and a limonitic pseudomorph after glauconite (*g*). × 165.

FIG. 9. Fragment of micaceous glauconite (*g*) altering first to limonite (opaque) and later to montmorillonite (*c.m.*) along cleavage planes. × 165.

Alteration of glauconite to limonite is common but its alteration to a clay mineral is unusual. The evidence presented by the glauconite in the Olmstead fuller's earth suggests two possibilities, first, that the glauconite changes to montmorillonite through an intermediate limonitic stage, and second, that it alters directly to montmorillonite. In support of the first possibility is the occurrence of glauconitic grains partly altered to both limonite and montmorillonite, the montmorillonite evidently succeeding the limonite. Supporting the second possibility is the occurrence of glauconite grains apparently altered directly to montmorillonite. If the limonitic intermediate stage is essential for the change from glauconite to montmorillonite, it must have been completely eliminated from those grains where the glauconite apparently changes directly to montmorillonite. Inasmuch as the iron content of glauconite varies from 16 to 30 per cent.,[9] whereas the Olmstead montmorillonite contains not more than 4.5 per cent. iron, it is evident that the alteration of glauconite to montmorillonite released an appreciable amount of iron, which is probably the source of the stained streaks and patches in the Olmstead earth.

The constituents of glauconite, other than iron, present no great problem in considering the alteration to montmorillonite. If in published analyses of glauconite, the proportions of iron be reduced to amounts comparable to those of the Olmstead montmorillonite, the proportions of Al_2O_3, SiO_2, MgO, CaO, and Na_2O, as correspondingly increased, are in some cases more and in some cases less than in the Olmstead montmorillonite, which suggests that none or only a small amount of some or all of these constituents was added or removed. The K_2O content of the glauconite is appreciably higher than that of the montmorillonite, which indicates that some of it was removed during the alteration, a process that would not be difficult, due to the easy solubility of potash.

Amorphous Silica.—Amorphous silica in irregular scattered particles constitutes 1 per cent. or less of the Olmstead earth.

[9] Schneider, H.: A Study of Glauconite. Jour. Geol., vol. 25, pp. 289–310, 1927.

Most of the particles are spherical or oval and cellular in structure, indicating an organic origin. A few of those whose origin cannot be determined are prismatic. The particles range up to .1 mm. in diameter and are mostly unaltered but a few of them are partly altered to montmorillonite (Fig. 10).

Other Minerals.—Albite, microcline, kyanite, tourmaline, zircon, rutile, epidote, sillimanite, staurolite, common hornblende, ilmenite, and leucoxene in the order of abundance, are irregularly scattered throughout the Olmstead fuller's earth. They occur in angular unaltered grains .06 mm. or less in size.

Texture.

All of the material composing the Olmstead earth except the amorphous silica and perhaps the secondary limonite is crystalline. The rock is made up of minute flake-like particles of montmorillonite that trend in all directions except around some of the larger mineral grains where it is uniformly oriented. This lack of orientation produces a matted texture which is believed to be responsible for the conchoidal fracture of the rock. The other minerals are scattered through the montmorillonite. The muscovite and micaceous glauconite show no uniformity of orientation.

The dry earth is porous. The individual pores are mostly too small to be seen, but their presence is indicated by the escape of many air bubbles when a fragment is immersed. The total porosity is probably increased by the random orientation of the montmorillonite flakes.

FULLER'S EARTH FROM LOCALITIES OUTSIDE OF ILLINOIS.

Chief Petrographic Features.

Peerless Clay and Metal Company, Creede, Colorado.—This material is composed of about 75 per cent. montmorillonite ($\gamma = 1.507$; $\gamma - \alpha = .02$; (—); 2V small), 20 per cent. fragmentary glass, and 5 per cent. quartz, microcline, orthoclase, albite, amphibole, and biotite. The montmorillonite occurs in

crystalline particles a micron or less in size without appreciably uniform orientation. The glass occurs as crescentic and lunar shards, in variable degrees of alteration to montmorillonite, the shard structures being preserved. The material is therefore a bentonite. The grains of quartz, microcline, orthoclase, albite, amphibole, and biotite reach a maximum diameter of .1 mm. and except the quartz are partly altered to montmorillonite (Fig. 11).

Filtrol Company, Tehachapi, California.—This earth is composed almost entirely of montmorillonite ($\gamma = 1.506$; $\gamma - \alpha = .021$; (—); 2V small), which occurs in crystalline flakes and particles with a maximum size of .02 mm., fairly well oriented with the long direction parallel to the bedding. Some of the flakes are twisted, suggesting that they may have been produced by the alteration of volcanic glass. The material also contains a very few grains of quartz having a diameter of .03 mm. A very few small round particles appear to be glass but it is not possible to determine positively whether or not the material is a bentonite (Fig. 12).

Filtrol Company, Chambers, Arizona.—The material is composed of about 90 per cent. montmorillonite ($\gamma = 1.490$; $\gamma - \alpha = .02$ (—); 2V small) and 10 per cent. orthoclase, microcline, albite, amphibole, muscovite, and quartz. The montmorillonite

FIGURES 10–15. PHOTOMICROGRAPHS OF FULLER'S EARTH.

FIG. 10. Shows in center a mass of amorphous siliceous cellular organic material, partly altered to montmorillonite. Olmstead, Ill. × 125.

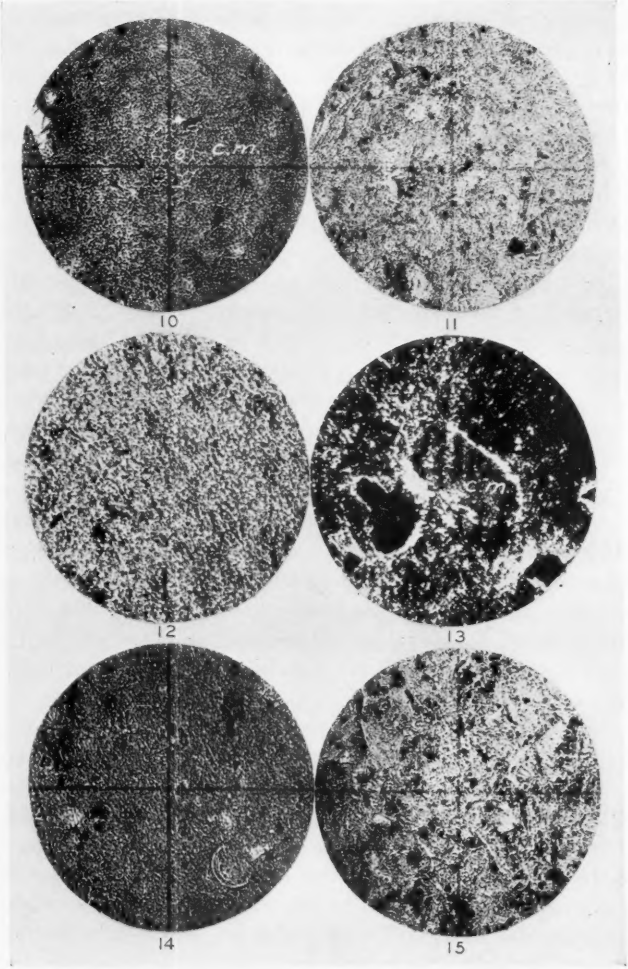
FIG. 11. Shows ash structure indicating bentonite. Creede, Colo. × 65.

FIG. 12. Shows matted texture produced by relatively large montmorillonite particles. Tehachapi, Cal. × 125.

FIG. 13. Shows aggregates of montmorillonite (*c.m.*), either pseudomorphic after detrital minerals or original detrital aggregates. Chambers, Ariz. X-nicols, × 125.

FIG. 14. Shows crescentic, altered, isotropic particle that appears to be an ash fragment but may be organic, so that the bentonitic origin of the earth is uncertain. Ocala, Florida. × 125.

FIG. 15. Shows well-preserved ash structures indicating bentonite Bath, England. × 65.


C.m.
10
11
12
13
14
15

occurs in crystalline flakes and particles with a maximum size of .005 mm. and without uniform orientation. Thin sections show large, round to rectangular areas of montmorillonite that stand out from the remainder of the matrix. Whether these structures are completely altered original minerals, aggregates formed at the time of accumulation of the sediment, or the result of some post-depositional process, can not be determined. The non-clay minerals are mostly about .06 mm. in size but some of them have a diameter of .5 mm. They show variable degrees of alteration to montmorillonite (Fig. 13).

. *Superior Earth Company, Ocala, Florida.*—This material is composed of about 90 per cent. montmorillonite ($\gamma = 1.524$; $\gamma - \alpha = .022$; (—); 2V small) and 10 per cent. fragments of isotropic siliceous material and grains of quartz, albite, and microcline. The montmorillonite occurs in minute crystalline particles a micron or less in size, which show slight uniformity of orientation. Many of the fragments of isotropic material which have a maximum diameter of .12 mm. have a cellular structure suggesting that they are organic remains; others strongly resemble bubble and shard remnants of volcanic glass. They show all degrees of alteration to montmorillonite. The quartz, albite, and microcline grains reach a maximum diameter of .06 mm. They show little or no alteration. The material examined presents strong evidence that this earth is at least in part bentonitic (Fig. 14).

Death Valley, Nevada (*Material Received from P. G. Nutting*).—This material is composed of about 95 per cent. montmorillonite ($\gamma = 1.514$; $\gamma - \alpha = .023$; (—); 2V small) and 5 per cent. unaltered grains of quartz, albite, and orthoclase, with a maximum diameter of .08 mm. The montmorillonite occurs mainly in non-uniformly oriented crystalline particles too small for size or shape determination and in flake-like particles with a maximum diameter of .06 mm. and a fair degree of uniformity of orientation.

Japanese Acid Clay (*Material Received from P. G. Nutting*).—Only powdered material was available. It is composed of

montmorillonite ($\gamma = 1.512$; $\gamma - \alpha = .023$ (—); 2V small).

Terrana earth (Acid-treated German Bleaching Clay).—Only powdered material was available for study. It is composed of montmorillonite ($\gamma = 1.506$; $\gamma - \alpha$ .024; (—); 2V small) and a very few minute grains of quartz.

English Fuller's Earth from near Bath.—This material is composed of 95 per cent. montmorillonite ($\gamma = 1.502$; $\gamma - \alpha = .021$; (—); 2V small) and 5 per cent. quartz, orthoclase, and amphibole, in fragments with maximum diameters of .06 mm. The montmorillonite occurs in crystalline particles varying to .1 mm. in size. The shape of the smaller ones can not be determined, but the larger ones are flaky and show little uniformity of orientation. Orthoclase and amphibole show some alteration to montmorillonite. Glass shards are also present and are excellently preserved. Pseudomorphs of montmorillonite after glass fragments are also perfectly preserved. The earth can be designated as a bentonite (Fig. 15).

Fuller's Earth Company, Midway, Gadsden County, Florida.—This earth is composed almost entirely of montmorillonite ($\gamma = 1.534$; $\gamma - \alpha = .023$; (—); $2V = 8° \pm$), which occurs in crystalline particles too small for size or shape determinations but showing a high degree of uniformity of orientation. A few quartz grains having a diameter of .06 mm. and a few minute flakes of muscovite are also present.

Western Clay and Metals Company, Ivey, Utah.—About 50 per cent. of this material is montmorillonite ($\gamma = 1.507$; $\gamma - \alpha = .022$; (—); ?) occurring in small crystalline particles which show slight uniformity of orientation. Structures indicating that at least some of the montmorillonite has been produced by the alteration of volcanic glass are excellently preserved. The remainder of the rock is composed chiefly of fragments of microcline and sodic plagioclase reaching several millimeters in diameter and partly altered to montmorillonite. Fragments of biotite and grains of ferro-magnesian minerals too highly altered to permit specific identifications are also present. A few grains of quartz occur.

Standard Fuller's Earth Company, Bexar County, Texas.—About 95 per cent. of this material is montmorillonite ($\gamma = 1.514$; $\gamma - \alpha = .022$; (—); 2V small), which occurs in crystalline particles and flakes with a maximum size of .02 mm. and little uniformity of orientation. The lack of orientation and the flake-like character of the larger particles produce a matted texture which resembles that produced by the alteration of glass. Angular to round particles of isotropic material reaching a maximum diameter of .04 mm. are concentrated in parts of the rock, where they make up as much as 25 per cent. of the total. These particles are usually too small for a specific determination, but they appear to be amorphous silica of organic origin. A very few grains of quartz having a maximum diameter of .05 mm. are also present. The material may be bentonite.

General Reduction Company, Twiggs County, Georgia.—About 90 per cent. of this earth is montmorillonite ($\gamma = 1.517$; $\gamma - \alpha = .022$; (—); $2V = 10° \pm$), which occurs in crystalline particles and flakes having a maximum size of .005 mm. with uniform orientation. The remainder of the rock is composed of grains of quartz with a maximum diameter of .04 mm., flakes of muscovite with a maximum diameter of .12 mm., and grains of glauconite with a maximum diameter of .04 mm. The flakes of muscovite grade to montmorillonite along their boundaries.

Attapulgus Fuller's Earth Company, Attapulgus, Georgia.—This material is composed of about 95 per cent. montmorillonite ($\gamma = 1.534$; $\gamma - \alpha = .022$; (—); $2V = 10° \pm$) in small crystalline particles uniformly oriented and 5 per cent. of quartz in angular, scattered grains with a maximum diameter of .05 mm.

Floridin Company, Quincy, Florida.—About 70 per cent. of this earth is montmorillonite ($\gamma = 1.532$; $\gamma - \alpha = .021$; (—); 2V small), in small crystalline particles some of which have a diameter of .01 mm. They are uniformly oriented. Veinlets and grains of calcite constitute about 20 per cent. of the rock. The calcite grains have a maximum diameter of .5 mm. The remainder of the rock is made up of quartz grains .12 mm. in maximum diameter, flakes of muscovite .12 mm. in maximum

diameter, and grains of glauconite .25 mm. in maximum diameter, irregularly scattered through the montmorillonite.

X-RAY ANALYSES.

X-ray analyses of purified samples of the clay mineral in the earths from Attapulgus, Georgia; Twiggs County, Georgia; Ivey, Utah; and Bexar County, Texas, were made by Dr. W. A. Sisson, University of Illinois. The diffraction patterns and computations are identical with those of typical montmorillonite, which confirms the identifications determined from optical data. The absence of any additional lines in the diffraction patterns indicates that the clay mineral is one definite crystalline mineral and not a mixture of several constituents.

PETROGRAPHIC DATA BEARING ON THEORIES OF DECOLORIZING ABILITY.

Several theories,[10] based on various data, have been advanced to explain the decolorizing ability of fuller's earth, but any worthwhile theory must take into account physical, chemical, and petrographical factors. A study of clays known to have bleaching ability has revealed some petrographic factors that should be considered in the development of such theories.

(1) Generally fuller's earths are made up of crystalline components except for very small quantities of glass and amorphous silica in some earths, and therefore its decolorizing ability cannot be ascribed to the presence of amorphous material.

(2) The clay mineral is the active constituent of the earth, and the other minerals may be regarded as adulterants. Unless the earth is extremely pure, an analysis of the bulk material will not reveal the composition of the active component, and therefore in general will not indicate whether or not an earth has bleaching properties. As the clay mineral is the active constituent, some

[10] Porter, J. T.: Properties and Tests of Fuller's Earth. U. S. Geol. Survey, Bull. 315, pp. 268–290, 1907. Parsons, C. L.: Fuller's Earth. U. S. Bur. Mines, Bull. 71, 36 pp., 1913. Shearer, H. K.: Fuller's Earth Deposits of the Coastal Plain of Georgia. Ga. Geol. Survey, Bull. 31, 1917. Nutting, P. G.: The Bleaching Earths. Ind. and Eng. Chem. Anal. Ed., vol. 4, pp. 139–141, 1932.

earths, notably the English and the Utah earths, are purified before use, and this is one of the reasons why others, such as the Terrana earth, are treated with acid.

(3) All of the fuller's earths described contain montmorillonite. Smectite, which in some textbooks on mineralogy has been considered the constituent of fuller's earth, is identical with montmorillonite.[11]

However, it has not been established that montmorillonite is the only clay mineral possessing bleaching ability and that therefore all fuller's earths are montmorillonite clays; on the contrary, certain Texas fuller's earths contain a clay mineral similar to but not identical with montmorillonite [12] and other earths not described may contain different types of clay minerals.

It seems certain that crystal structure, cleavage, adsorption ability, base-exchange capacity, chemical composition, etc., of certain clay minerals, notably montmorillonite, give them the property of decolorizing oils or permit them to be activated so that they gain decolorizing ability.

(4) In most of the earths examined the clay mineral particles were too small to be measured but probably were a micron or less in size, although particles having a maximum diameter of several hundredths of a millimeter are abundant in some earths. The larger particles appear to be micaceous, and it is possible that during decolorization the larger flakes split into smaller ones if small particle size is necessary for decolorizing ability. Other clays without bleaching ability contain the same quantity of the same size of other clay mineral particles, so that size of constituent particles does not appear to be a controlling factor although it may be a contributing factor in that it governs the amount of clay mineral easily accessible to the material being decolorized.

(5) The larger clay mineral particles are flake-like and micaceous, so that the smaller ones probably have the same form. In an attempt to account for the properties of bentonite, it has

[11] Kerr, P. F.: Montmorillonite or Smectite as Constituents of Fuller's Earth and Bentonite. Amer. Min., vol. 17, pp. 192–198, 1932.

[12] Broughton, M. N.: Texas Fuller's Earths. Jour. Sed. Petrology, vol. 2, pp. 135–140, 1932.

been suggested [13] that the clay mineral particles are probably flakes of colloidal thickness but larger in other dimensions. Examination of the material in thin section provides data agreeing with this conclusion.

(6) Fuller's earth has no characteristic texture. In many thin sections the individual clay particles show no uniformity of orientation whereas in others the uniformity of orientation is almost perfect. In the first case, an appreciable but undeterminable amount of pore space is strongly suggested but in the other case there is no evident porosity. The powdering of the earth before use and the probable disaggregation of the clay fragments during use seem to eliminate texture as an essential factor in decolorizing but it may be a contributing factor insofar as it controls the ease of access to the clay particles.

(7) The decolorizing ability of bleaching clays seems to be independent of their genesis. The Olmstead earth is a near-shore marine sediment, the deposit of the Filtrol Company at Chambers, Arizona, is a terrestrial deposit,[14] and the earth from Ivey, Utah, is a decomposed dacitic breccia underlying conglomerates that are at least in part fluviatile.[15] Some deposits of fuller's earth are produced by *in situ* decomposition of basic igneous rocks.[16] Decolorizing material has been obtained from glacio-lacustrine deposits in Massachusetts.[17]

Some fuller's earths have had a bentonitic origin. Other earths do not appear to be bentonites.

ILLINOIS GEOLOGICAL SURVEY,
URBANA, ILL.

[13] Wherry, E. T.: Bentonite as a One-dimensional Colloid. Amer. Min., vol. 10, pp. 120–123, 1925.

[14] Tenney, J. B.: The Mineral Industries of Arizona. Ariz. Bur. of Mines, Bull. 129, p. 93, 1930.

[15] Crawford, A. L.: Personal communication.

[16] Miser, H. D.: Developed Deposits of Fuller's Earth in Arkansas. U. S. Geol. Survey, Bull. 530, pp. 207–220, 1913. Roggatt, H. G.: Fuller's Earth in N. S. Wales. Geol. Survey of N. S. Wales, Bull. 14, pp. 15–18, 1924.

[17] Alden, W. C.: Fuller's Earth and Brick Clays near Clinton, Mass. U. S. Geol. Survey, Bull. 430, pp. 402–404, 1910.

THE APPLICATION OF THE QUARTZ SPECTROGRAPH TO THE STUDY OF OPAQUE MINERALS.[1]

MAURICE HALL HAYCOCK.

CONTENTS.

Introduction 364
Method of Analysis by Means of the Quartz Spectrograph 366
The Standard Solutions 369
Production of the Standard Reference Spectra 369
Preparation of the Sample 371
Production of the Spectra of the Solutions Containing the Unknowns 372
Qualitative Analysis of the Spectra of the Unknowns 373
Quantitative Analysis of the Spectra of the Unknowns 373
Application of the Method 376
The Material Studied 376
Unknown No. 1 376
Unknown No. 2 377
Unknown No. 3 379
Unknown No. 4 381
Summary 382

INTRODUCTION.

In the course of mineragraphic studies difficulty is commonly encountered in determining opaque minerals that occur as very small isolated grains or in intimate intergrowths. Frequent references in the literature to "unknown" minerals testify to the limitations of our present determinative technique, and indicate the desirability of more efficient methods of determination. Within the last two decades many such methods have been developed, each contributing toward overcoming this difficulty. Several papers have recently appeared concerning the application

[1] A dissertation presented to the Faculty of Princeton University in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

of spectrographic methods to the quantitative determination of minor metallic constituents in ores.[2]

Except in one instance,[3] however, little use has so far been made of these methods as a means of determining those elements which occur as essential constituents of metallic minerals.

The present investigation was begun during the study of certain copper-nickel ores that were known to contain appreciable amounts of the platinum-group metals. The problem of determining ore minerals that occur in minute quantities was immediately recognized and, on the suggestion of Professor Edward Sampson, an attempt was made to apply the quartz spectrograph to its solution, with the result that a method was developed and applied to " unknowns " in ores from several localities. The following statements are presented in the belief that they indicate that the spectrograph promises real aid in determining ore minerals where exceedingly small samples only are available.

The writer wishes to express his gratitude and appreciation for the many favors accorded him by the Faculty of Geology of Princeton University. He is especially grateful to Professor Edward Sampson for his many generous contributions. He wishes to express also his indebtedness to Professor A. G. Shenstone of the Department of Physics of Princeton University for his coöperation in placing at the writer's disposal the equipment necessary for the spectrographic analyses and for his generous guidance and advice; to Miss Jane Dewey of the Department of Geology of Rochester University for the loan of a manuscript in which are set forth the results of her investigations concerning the use of the quartz spectrograph in the determination of the feldspars; and to Dr. M. N. Short of the U. S. Geological Survey,

[2] Schneiderhöhn, H., in Wagner, P. A.: The Platinum Deposits and Mines of South Africa, pp. 231–238, 1929.

Moritz, H.: Über einige Erfahrungen im Gebrauch des Quartzspektrographen zur Feststellung spurenweise auftretender Elemente. Metall und Erz, Heft 10, pp. 247–50, 1929.

Cissarz, A.: Die durchschnittliche Zusammensetzung des Mansfeld Kupferschiefers. Metall und Erz, Heft 12, pp. 316–319, 1930.

Cissarz, A.: Quantitativ-spektralanalytische Untersuchung eines Mansfelder Kupferschieferprofils. Chemie der Erde, 5, pp. 48–75, 1930.

[3] Schneiderhöhn, H.: *op. cit.*

for his kindness in giving freely of his time in acquainting the writer with microchemical methods, a knowledge of which was essential in the preparation of the samples for analysis, and for kindly consenting to read the manuscript of this paper.

METHOD OF ANALYSIS BY MEANS OF THE QUARTZ SPECTROGRAPH.

Analysis by means of the quartz spectrograph is of such a nature that different workers have varied considerably in the details of technical procedure; so much has been written on the subject that an adequate review would require more space than is available. The investigator who desires to apply such methods is, therefore, advised to acquaint himself with the literature, many references to which will be found in the more important and general sources quoted below.[4]

The fundamental principle upon which spectroscopy is based is that any element, when vaporized and excited either electrically

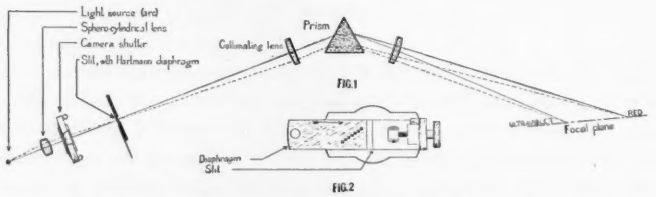


FIG. 1. Diagram of the quartz spectrograph, showing the passage of light from the source to the photographic plate.

FIG. 2. Diagram of 7-hole Hartmann diaphragm moved to the left to uncover the slit of the spectrograph.

or by high temperature, emits light, the component wave-lengths of which are characteristic of that element. The quartz spectrograph is an instrument which records on a photographic plate

[4] An excellent summary of quantitative methods appears in a paper by Charles C. Nitchie entitled "Quantitative Analysis with the Spectrograph," Ind. and Eng. Chem. (Analytical Edition), vol. 1, no. 1, pp. 1–7, 1929.

Löwe: Atlas der Letzten Linien der Wichtigsten Elementen. Steinkopff, Dresden and Leipzig, 1928.

Bulletin of Spectrum Analysis, published by Adam Hilger, London. This publication gives much useful information of a general nature.

the component wave-lengths of the light emitted by a source, the optical system being constructed of quartz in order to transmit the ultra-violet portion of the spectrum. The light is admitted to the instrument through a narrow slit, whence it passes through a collimating lens to a prism (Fig. 1). In passing through this prism the components of different wave-length are differentially refracted, the direction of the short wave-lengths being altered more than that of the long ones. The refracted light then passes through a second lens which focuses it on a photographic plate, the position of a line on the plate depending on the wave-length of the light which produced it.

The instrument used throughout the present investigation was a type E–2 quartz spectrograph manufactured by Adam Hilger, London. The advantage of this medium-sized instrument over the larger ones, lies in the fact that the whole spectrum from about 2000A [5] to about 8000A is recorded during one exposure, whereas in the larger types several ranges, and hence several exposures, are required to cover the spectrum. The light from a direct current arc was focused on the slit by means of a quartz

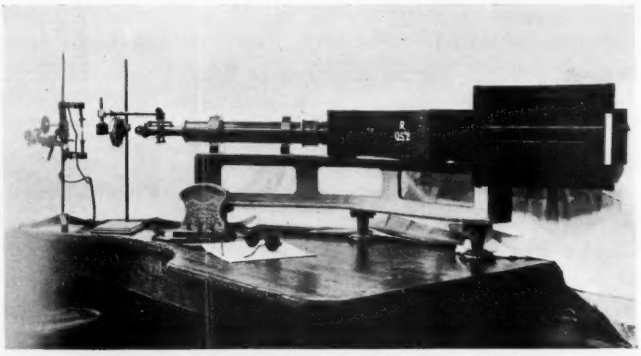


FIG. 3. Photograph showing the quartz spectrograph, with camera shutter, spherocylindrical lens, and arc lamp in position.

[5] The position of a line in the spectrum is indicated by the wave-length of the vibration which produces it. An Angström unit, or "Angstrom" (A) equals 10^{-10} metre, or 0.0001 μ where μ is the micron, or thousandth part of a millimeter.

spherocylindrical lens. An ordinary camera shutter, placed between this lens and the slit, served to control the length of the exposure.

In general, spectrographic analyses are of two types, qualitative and quantitative. The method of performing qualitative analyses is comparatively simple and consists in photographing the spectra of the unknowns and identifying the lines. The positions of the lines on the plate are a measure of their wave-lengths, and identification may be made either by comparison with the spectra of known elements, or by obtaining the wave-lengths of the lines by means of a measuring microscope designed for the purpose, and referring to wave-length tables of the lines of the elements.[6]

Methods of quantitative analysis, on the other hand, are complicated and require carefully controlled conditions. All the various methods are based upon the fundamental principles that (1) other conditions remaining constant, the number and intensity of the lines of an element recorded by the photographic plate decrease with decreasing concentration of that element in the source, and (2) other conditions remaining constant, the time required for the disappearance of all but the ultimate lines [7] of an element depends upon the amount of that element in the source. The method employed most widely is to compare the spectra of the unknown with the spectra produced by known amounts of the element to be determined. An estimate of the amount of the element present is then made on the basis of intensity and number of lines.

The method followed in the present investigation was likewise based on these principles. A unit volume solution containing an unknown was introduced into the arc and its spectrum photographed. From this a qualitative analysis was made; then the

[6] Löwe: Atlas der Letzten Linien der Wichtigsten Elementen. Steinkopff, Dresden and Leipzig, 1928.

Kayser, H.: Tabelle der Hauptlinien der Linienspektra aller Elements. Julius Springer, Berlin, 1926.

Kayser and Konen: Handbuch der Spectroscopie, vols. 7 and 8. S. Hirzel, Leipzig, 1924.

[7] The ultimate lines of an element are the last lines to disappear from the spectrum with decreasing amount of that element in the source. They were called the "persistent lines" by Hartley and "raies ultimes" by de Gramont.

spectra of unit volumes of standard solutions of the elements appearing in the unknown were photographed, and the concentrations of those elements in the unknown estimated by comparison.

The Standard Solutions.—A separate series of solutions of known concentration was prepared for each element to be determined in the unknowns. Wherever possible, the metals were taken into solution as chlorides by dissolving *one gram atomic weight* of the metal as chloride in one liter of distilled water. This usually resulted in normal solutions from which the remainder of the series was produced by diluting to the desired normality. The reason for using solutions of known *normality* was as follows: Percentages could not be determined for two reasons: (1) the samples available were so small (usually only a fraction of a milligram) that it was impossible to weigh them, and (2) sulphur has no arc lines in the region of the spectrum covered by the quartz spectrograph and can not be determined. Thus, when two or more elements in the solution, containing the unknown, produce lines, their relative concentrations expressed in terms of normality of the solution to which they are compared represent their *atomic ratios.* Since it was found that when a consistent method of sampling was followed, the concentrations of the elements in the solutions containing the unknowns usually fell between normalities of N/2 and N/200, ten solutions of the following concentrations were made up for each element to be determined: N/1, N/2, N/4, N/6, N/10, N/20, N/40, N/60, N/100, and N/200. In exceptional cases it was necessary to supplement these with solutions of concentrations of N/400, N/600, and rarely, N/1000.

Production of Standard Reference Spectra.—The direct current arc was employed in the production of the reference spectra as well as in the production of the spectra of the solutions containing the unknowns. Pure graphite electrodes[8] ¼ inch in diameter and 1½ inches in length were shaped with a pencil

[8] The graphite electrodes used in this case were obtained from the Acheson Graphite Corporation, Niagara Falls, New York.

sharpener and mounted in the lamp as shown in Fig. 4, *A*. They were then burned for about a minute to remove any impurities due to handling, and to produce porosity in the graphite to

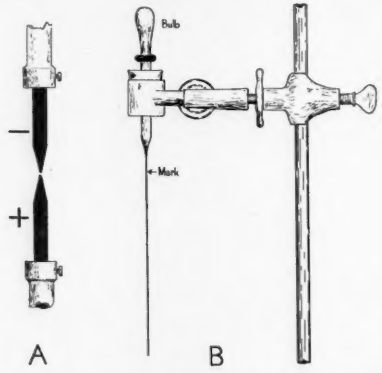


FIG. 4. *A*. Method of mounting and shaping the electrodes. × 1/3. *B*. The capillary tube used in the measurement of the solutions. × 1/3.

facilitate the absorption of the solution. After the electrodes cooled, a carefully measured volume of the solution was run onto the lower electrode by means of a 4-inch capillary tube (Fig. 4, *B*). This tube, when filled to a mark, contained approximately 0.002 cc. of solution, which was expelled by means of a rubber bulb.[9] The electrode was then allowed to dry for two hours in an electric oven with the temperature at about 50° C.

The series of photographs was made by using ten solutions, one for each concentration of the element and each on a separate pair of electrodes. With each solution from three to seven exposures were made, depending upon their concentration. The shifting of the image of each successive exposure to a new position on the photographic plate is accomplished by means of a seven-hole Hartmann diaphragm (Fig. 2) which is moved across the slit of the spectrograph in such a manner that in seven dif-

[9] It was found useful to compress and release the bulb by means of a small screw clamp. In this way the control was very delicate.

ferent positions, seven different portions of the slit are open for the passage of light. Between each set of seven exposures, the plate is shifted to a new position by means of a sliding plate-holder. In this way a series of exposures is obtained such that the spectrograms are perfectly registered with respect to each other.

In photographing a set of exposures, the first or upper exposure is made of blank graphite electrodes in order to determine the lines caused by impurities. The succeeding exposures, with the electrode impregnated with the standard solution, were made in the following manner: The first exposure is begun by striking an arc between the electrodes with the shutter open. At the end of 10 seconds the shutter is closed and an interval of 20 seconds is allowed to elapse before it is again opened for a 10-second period, the image being shifted to a new position by moving the Hartmann diaphragm between the exposures. This operation is repeated for the remaining exposures of the series. The arc is burned constantly during the production of the set, the current being kept as closely as possible to 4.0 amperes.

Remarkable consistency is shown in the decrease in intensity, number and persistence of the lines with decrease in concentration of the element in solution. Commonly most of the lines have disappeared by the second or third exposure, and only the ultimate lines persist throughout the whole series. For this reason the number of reference plates is not large, since five sets are made on one photographic plate.

Preparation of the Sample.—The sample of the "unknown" to be determined is obtained from the polished section in the manner previously described by the writer,[10] by which sufficient material is obtained by boring out the central portions of from 5 to 10 grains with cross-sections of about 0.5 mm., or an equivalent amount. The borings are transferred to a drop of distilled water placed on a glass slide, where the material is dissolved by repeated evaporations with 1 : 1 nitric acid. The evaporations are carried out carefully over a small alcohol lamp. When solution is com-

[10] Haycock, M.: A Method for Sampling Minerals in Polished Sections. Econ. Geol., vol. 26, pp. 415–420, 1931.

plete (except for the sulphur, which usually separates as a small globule), the nitric acid is evaporated off and the residue dissolved and evaporated several times with 1 : 1 hydrochloric acid, and finally dissolved in 1 : 8 hydrochloric acid. This conversion of the nitrates to chlorides is brought about in order to produce a solution as nearly as possible comparable to the standard solutions.

Where minerals that resist solution in nitric acid are encountered, they are first subjected to repeated evaporations with aqua regia, after which the residues are converted to chlorides as outlined above.

Complications arose in the case of certain elements that form insoluble chlorides, notably silver and lead. For some reason not at present clear, the nitric acid solutions of silver show only very weak lines in high concentrations and none whatever in low concentrations. The same solutions, when the silver nitrate is converted to silver chloride, produced more intense spectra. Hence, after the silver nitrate is placed on the electrode, a small amount of hydrochloric acid is added. The results of this conversion to chlorides on the electrode are not as consistent as when the element is placed on the electrode as a soluble chloride, and so far no satisfactory method of eliminating this variable factor has been devised.

Production of the Spectra of Solutions Containing the Unknowns.—The spectrograms of the solutions that contain the unknowns are produced in the same manner as are those of the standard solutions. In the preparation of the electrodes the same procedure is followed, and the exposures of the impregnated electrode are made in the same way. A slight variation is introduced, however, in that before this set is photographed, two preliminary spectra are taken: the first is produced by the graphite with the solvent used to dissolve the mineral, in order to detect any impurities; the second is produced by a powder containing nearly all the elements in such proportions that their ultimate lines are recorded,[11] providing a reference spectrum by means of which a rapid identification of the elements in the unknown can usually

[11] R. U. ("raies ultimes") Powder, developed in the Research Laboratories of the General Electric Company, and procurable through Adam Hilger, London.

be made. The remaining five exposures are made of the unknown.

Qualitative Analysis of the Spectra of the Unknowns.—The lines present in the spectrum of the unknown are first identified. Most of these lines can usually be assigned to an element at sight, by the simple method of comparing the spectrum with that of the R. U. powder. The positions of those lines which can not be placed in this manner are measured by means of a measuring microscope, and with the known lines as reference points, their wave-lengths are calculated after the method outlined in a pamphlet published by Adam Hilger, London.[12] The elements to which the lines belong are then determined from the wave-length tables already referred to.

Quantitative Analysis of the Spectra of the Unknowns.—Since equal volumes of the standard solutions and of the solutions containing the unknowns are used, it follows that in the spectra produced, the number and intensity of the lines, as well as the time required for their disappearance, depends upon the concentrations of those elements *in the impregnated zone of the graphite electrode, which in turn depends upon the initial concentrations of those elements in the original solution.* With this in mind, the spectrum of each element present in the unknown is compared with the spectra of the standard solutions for that element, until one of the latter is found to match, or until two adjacent standard spectra are found to lie, one above and one below, the spectrum of the element in the unknown. The result of this comparison is to obtain an approximate estimate of the concentration of each element in the unknown, expressed in terms of normality. From this, the approximate atomic ratios are obtained.

It has been found that elements in a source exert a mutual influence on one another, in certain instances very marked, in others very slight. In view of this fact, it is considered necessary to check the results, especially where the identification of a mineral depends upon the atomic ratios of the elements present. A standard solution is therefore prepared of all the elements in the un-

[12] The Practice of Spectrum Analysis with Hilger Instruments (2d ed.), pp. 21–23.

plete (except for the sulphur, which usually separates as a small globule), the nitric acid is evaporated off and the residue dissolved and evaporated several times with 1 : 1 hydrochloric acid, and finally dissolved in 1 : 8 hydrochloric acid. This conversion of the nitrates to chlorides is brought about in order to produce a solution as nearly as possible comparable to the standard solutions.

Where minerals that resist solution in nitric acid are encountered, they are first subjected to repeated evaporations with aqua regia, after which the residues are converted to chlorides as outlined above.

Complications arose in the case of certain elements that form insoluble chlorides, notably silver and lead. For some reason not at present clear, the nitric acid solutions of silver show only very weak lines in high concentrations and none whatever in low concentrations. The same solutions, when the silver nitrate is converted to silver chloride, produced more intense spectra. Hence, after the silver nitrate is placed on the electrode, a small amount of hydrochloric acid is added. The results of this conversion to chlorides on the electrode are not as consistent as when the element is placed on the electrode as a soluble chloride, and so far no satisfactory method of eliminating this variable factor has been devised.

Production of the Spectra of Solutions Containing the Unknowns.—The spectrograms of the solutions that contain the unknowns are produced in the same manner as are those of the standard solutions. In the preparation of the electrodes the same procedure is followed, and the exposures of the impregnated electrode are made in the same way. A slight variation is introduced, however, in that before this set is photographed, two preliminary spectra are taken: the first is produced by the graphite with the solvent used to dissolve the mineral, in order to detect any impurities; the second is produced by a powder containing nearly all the elements in such proportions that their ultimate lines are recorded,[11] providing a reference spectrum by means of which a rapid identification of the elements in the unknown can usually

[11] R. U. ("raies ultimes") Powder, developed in the Research Laboratories of the General Electric Company, and procurable through Adam Hilger, London.

be made. The remaining five exposures are made of the unknown.

Qualitative Analysis of the Spectra of the Unknowns.—The lines present in the spectrum of the unknown are first identified. Most of these lines can usually be assigned to an element at sight, by the simple method of comparing the spectrum with that of the R. U. powder. The positions of those lines which can not be placed in this manner are measured by means of a measuring microscope, and with the known lines as reference points, their wave-lengths are calculated after the method outlined in a pamphlet published by Adam Hilger, London.[12] The elements to which the lines belong are then determined from the wave-length tables already referred to.

Quantitative Analysis of the Spectra of the Unknowns.—Since equal volumes of the standard solutions and of the solutions containing the unknowns are used, it follows that in the spectra produced, the number and intensity of the lines, as well as the time required for their disappearance, depends upon the concentrations of those elements *in the impregnated zone of the graphite electrode, which in turn depends upon the initial concentrations of those elements in the original solution.* With this in mind, the spectrum of each element present in the unknown is compared with the spectra of the standard solutions for that element, until one of the latter is found to match, or until two adjacent standard spectra are found to lie, one above and one below, the spectrum of the element in the unknown. The result of this comparison is to obtain an approximate estimate of the concentration of each element in the unknown, expressed in terms of normality. From this, the approximate atomic ratios are obtained.

It has been found that elements in a source exert a mutual influence on one another, in certain instances very marked, in others very slight. In view of this fact, it is considered necessary to check the results, especially where the identification of a mineral depends upon the atomic ratios of the elements present. A standard solution is therefore prepared of all the elements in the un-

[12] The Practice of Spectrum Analysis with Hilger Instruments (2d ed.), pp. 21–23.

known in the approximate estimated concentrations. The spectrum of this solution is then photographed and compared with the spectrum of the unknown.

It may be noted in passing that the solutions used to check the concentrations in the unknowns may be employed in the determination of the minor constituents. The procedure has been so well described by several authors[13] that reference only is here made to this phase of quantitative spectral analysis. The present study is entirely concerned with the determination of the major constituents.

Several points in connection with the application of the method outlined in this paper are worthy of note. Since the spectrum of each standard solution is produced by a different source at a different time, a high degree of consistency must be observed. Variation in any one of the following may produce inconsistent results:

1. The length, diameter, and shape of the electrodes. Any difference in these factors will alter the temperature of the arc, both because of the effect on the potential drop and because of the rate of conduction of heat away from the points. Moreover, if sharp angles are present at the points, a high potential may occur and introduce spark lines into the spectrum.
2. Distance between the electrodes. A variation in distance between the electrodes causes variation in the drop in potential.
3. Amperage of the current. Variation of the amperage causes variation in the drop in potential. It is to be noted that under the most favorable conditions, the arc will vary about 10 per cent. Generally speaking, the higher the voltage of the supply, the steadier the arc. Commensurate with safety of operation, the best results are thought to be obtained with voltages above 220, and many spectroscopists prefer voltages of 350 or even 700. The present work was done with a voltage of 110, a higher supply not being available.
4. Preparatory burning of the electrodes. Consistency on this point will produce electrodes of similar shape and porosity.
5. Volume of solution. This has previously been referred to in detail.
6. Procedure of adding the solution to the electrode. It is necessary to take care that the solution is absorbed by the *tip* of the electrode

[13]Nitchie, C. C., *op. cit.*, and others.

and not allowed to run down over the side. Therefore it must be added slowly.

7. Period of drying of impregnated electrode. Appreciable moisture remaining in the electrode will volatilize at the outset and affect the spectrum.
8. Position of the source with reference to the slit of the spectrograph. This is a common source of error, and care must be taken to keep the light accurately focused on and covering the slit.
9. Adjustments to the optical system of the spectrograph. Any changes in adjustment of slit and focus should be rigorously avoided.
10. Timing of exposures.
11. Type and make of plate. Variations in the sensitivity of photographic plates are different for different wave-lengths, and a standard make of plate should be adopted and used consistently.
12. Development of the plate. Consistency in development is probably best obtained by following a time-temperature method, taking care to use developer of fixed concentration.

Less precision is required in controlling the conditions under which the spectra of the solutions containing the unknown are produced, although in the present study every care was observed in duplicating them as far as possible. This is because slight variations in conditions produce similar variations in the behavior of all the elements present, since they are all present in the same source and their spectra are recorded simultaneously. Hence such minor variations do not affect the final estimate of their ratios.

It may appear that the number of standard solutions and reference plates necessary is beyond the realm of practicability. There are, however, several features that tend to minimize this difficulty. Once the solution of an element is made up to a normality of N/1, the dilution to the desired normalities for the standards is a simple and rapid procedure. Moreover, only a very small volume is necessary, and in the present case the standards were retained in ordinary closed tubes fitted with cork stoppers. It is impossible at present to say how long the solutions will keep under such conditions. As has previously been stated, in photographing the standard solutions, the spectra of five standards were placed on one plate. Since ordinarily ten standard

spectra will suffice for each element, only two plates are required. Furthermore, after the plates are produced, they form part of a reference library that requires no duplication.

APPLICATION OF THE METHOD.

The Material Studied.—The method, as outlined, was applied in the study of unidentified minerals in auriferous silver-lead ores from Alaska.[14] These ores have been described by W. B. Jewell [15] and by A. F. Buddington.[16] The veins containing the ores studied belong to a set of metalliferous quartz veins whose mineralogy ranges from that characteristic of high to that of intermediate temperatures. These veins occur within, or near the borders of, a stock of granodiorite. They characteristically contain gold, silver, lead and zinc. The minerals commonly encountered are pyrite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite, and tetrahedrite. All these minerals were present in the specimens studied, but the investigation was confined to the attempt to determine five unknown minerals, the properties of which were recorded by Jewell.[17] Definite information was obtained concerning three of these minerals, but two were present in grains so small that all attempts to obtain a sample of sufficient purity and size were fruitless. For the purpose of illustrating the limitations of the method at the time of writing, all five minerals will be treated.

Unknown No. 1 (Fig. 5).—"A strongly anisotropic mineral occurring as rounded blebs and spikes with typical emulsion structures in galena. Color—grayish white; pleochroism—in one position the mineral is a perfect match for galena, and in the other position can hardly be distinguished from tetrahedrite in color; hardness—same as galena; x nicols —strongly anisotropic, though no showing of color; etch tests—same as for tetrahedrite." [18]

[14] The writer is indebted to the Alaska Branch of the U. S. Geological Survey for the use of the material collected and studied by Jewell.

[15] Jewell, W. B.: Mineral Deposits of the Hyder District, Southeastern Alaska. ECON. GEOL., vol. 22, pp. 494–517, 1927.

[16] Buddington, A. F.: Geology of Hyder and Vicinity, Southeastern Alaska. U. S. Geol. Survey Bull. 807, 1929.

[17] Jewell, W. B.: *op. cit.*, p. 506, footnote 21.

[18] Jewell, W. B.: *op. cit.*, p. 506, footnote 21 (1).

All tests checked completely with those given by Jewell. The spikes and blebs are so small, however, that any attempt to isolate them resulted in a sample consisting essentially of the galena. Under these conditions, the spectrum showed only lead with a very minor amount of silver. It was estimated that the silver content was higher than would be expected to result from a solid solution of this metal in galena, indicating that the possibility of this being a silver mineral must be considered.

Unknown No. 2 (Fig. 6).—"A typical graphic intergrowth, both parts of which are distinctly anisotropic. One portion of the intergrowth is grayish white (between tetrahedrite and galena in color), while the other portion is the exact duplicate of galena in color. The intergrowth seems to occur exclusively along tetrahedrite-galena contacts. Etch tests for the grayish-white part of the intergrowth were as follows: HNO_3—neg.; HCl—neg.; KCN—very slowly faint brown; $FeCl_3$—neg.; $HgCl_2$—tarnishes dark brown, rubs almost clean; KOH—neg. Etch tests for the galena-white part of the intergrowth gave: HNO_3—like galena; HCl—like galena; KCN—neg.; $FeCl_3$—neg.; $HgCl_2$—tarnishes dark brown, rubs almost clean; KOH—neg."[19]

For the purpose of distinguishing between the two parts of the intergrowth, the grayish white mineral was designated "unknown 2-a" and the galena-white mineral "unknown 2-b." All the tests were found to check except the test for anisotropism on mineral 2-b; as far as the writer could ascertain this mineral is isotropic.

The intergrowth is so fine that the sample consists of an aggregate of the two minerals. The spectrographic analysis can therefore be only a rough estimate so far as the amounts of the elements present are concerned. The results are as follows: Sn—essential amount, probably higher than the lead; Pb—essential amount; Cu—trace. The presence of sulphur in small amount was detected during the solution of the sample.

From the similarity of the tests given for galena and those given by unknown No. 2-b, it is highly probable that this mineral is galena. A comparison of tests may be made from the following table:

[19] Jewell, W. B.: *op. cit.*, p. 506, footnote 21 (2).

TABLE I.

PROPERTIES OF UNKNOWN NO. 2-B AND GALENA.

Unknown No. 2-b.	Galena.*
Color—exact duplicate for galena	Galena white
Polarized light—isotropic	Isotropic
Etch Tests:	Etch Tests:
HNO_3—like galena	HNO_3—stains black
HCl—like galena	HCl—tarnishes brown to irridescent
KCN—neg.	KCN—neg.
$FeCl_3$—neg.	$FeCl_3$—tarnishes irridescent. This reaction is negative when galena is in contact with bornite
KOH—neg.	KOH—neg.
$HgCl_2$—tarnishes dark brown, rubs almost clean	$HgCl_2$—neg.

* The tests for galena are taken from M. N. Short's determinative tables.

It is almost certain, then, that the tin occurs in mineral 2-a of the intergrowth and is an essential constituent of it, and it is probable that the same may be said for some of the lead. The information is not indicative of whether sulphur also occurs in mineral 2-a.

By reference to determinative tables for the opaque minerals [20] it was found that only one tin mineral, *teallite*, bears marked resemblance to unknown No. 2-a. From this partial similarity, as shown in Table II., unknown 2-a is thought to be either teallite or a tin sulphide or tin-lead sulphide hitherto undescribed.

TABLE II.

PROPERTIES OF UNKNOWN NO. 2-A AND TEALLITE.

Unknown No. 2-a	Teallite *
Composition—Sn, with probably Pb, and S (?)	SnS.PbS
Color—grayish white	Galena white
Polarized light—distinctly anisotropic	Anisotropic
Etch Tests:	Etch Tests:
HNO_3—neg.	HNO_3—neg.
HCl—neg.	HCl—quickly tarnishes gray to brown
KCN—very slowly faint brown	KCN—neg.
$FeCl_3$—neg.	$FeCl_3$—neg.
KOH—neg.	KOH—neg.
$HgCl_2$—tarnishes dark brown, rubs almost clean	$HgCl_2$—neg.

* Tests for teallite taken from M. N. Short's determinative tables.

[20] Short, M. N.: Microscopic Determination of the Ore Minerals, U. S. Geol Survey Bull. 825, 1931.
Farnham, C. M.: Determination of the Opaque Minerals, 1931.

Unknown No. 3 (Fig. 7).—"A strongly anisotropic mineral, generally occurring as irregular grains or blades of microscopic size in galena. It is often associated with the graphic intergrowth. Color—practically the same as galena but sometimes slightly grayish; hardness—about that of galena; x nicols—strongly anisotropic, giving pale browns and blues; HNO_3—tarnishes dark like galena but more slowly; HCl—neg.; KCN—neg.; $FeCl_3$—neg.; $HgCl_2$—neg.; KOH—neg.[21]

In general the tests were found to check, but the description of the etch tests with HNO_3 should be supplemented by the following: After several seconds during which no effect is observed, an iridescent wave spreads from one side of an area of the mineral to the other, momentarily revealing a fine parallel structure, after which the surface turns rapidly dark with effervescence.

This mineral occurs in grains of sufficient size to permit of obtaining a pure sample. The result of the spectrographic analysis of the solution of this sample is as follows:

Pb—essential amount—conc. slightly above N/100
Sb—essential amount—conc. between N/200 and N/100, nearer N/100

Sulphur was detected during the solution of the mineral, in amounts sufficient to indicate that it also is an essential constituent. Qualitatively then, the mineral is indicated as being a lead sulphantimonide.

By reference to Short's determinative tables three possibilities were found; boulangerite, geocronite, and meneghinite. However, etch tests do not serve to distinguish which one of these three is to be identified as the mineral. The properties of these minerals are given in Table III., together with the properties of unknown No. 3.

The ratio of lead to antimony indicated by the normalities of these elements in the solution of the unknown is approximately 1 : 1, but slightly greater for the lead. The lead-antimony ratios in the three minerals cited as possibilities are:

	Pb : Sb Ratio	
Boulangerite	5 : 4	
Geocronite	10 : 4	(5 : 2)
Meneghinite	8 : 4	(4 : 2)

[21] Jewell, W. B.: *op. cit.*, p. 506, footnote 21 (3).

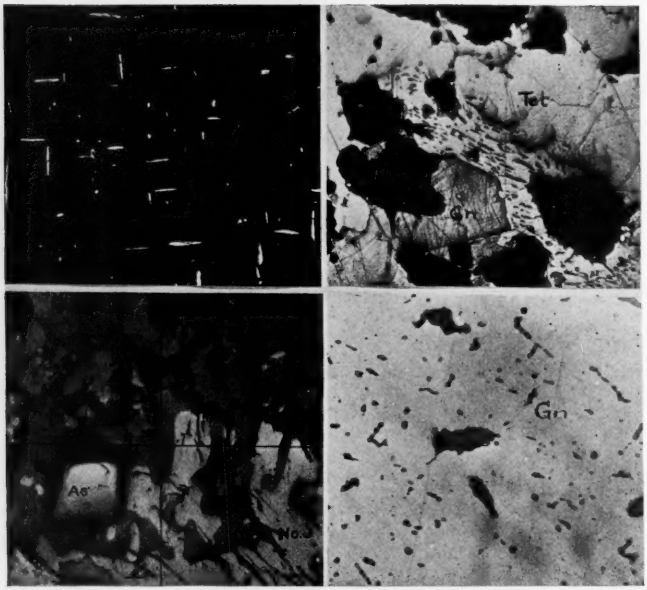


FIG. 5. Spikes and blebs of unknown mineral No. 1 in galena. Galena etched with HCl. ×70.

FIG. 6. Intergrowth of unknown minerals (No. 2). Intergrowth is localized between tetrahedrite (Tet) and galena (Gn). Galena and galena-white part of intergrowth etched with HCl. Sphalerite (Sl) occurs as residual grains in the tetrahedrite. Black areas are solution pits in the calcite gangue. ×78. (Photo by W. B. Jewell.)

FIG. 7. Boulangerite (unknown No. 3), associated with chalcopyrite (*Cp*), galena—etched with HCl (*Gn*), sphalerite (*Sl*), and arsenopyrite (*As*). ×130. (From photograph by W. B. Jewell.)

FIG. 8. Pyrargyrite (unknown No. 4), in galena (Gn). ×80.

A final distinction is therefore made, mineral 3 being indicated as *boulangerite.*

TABLE III.

PROPERTIES OF UNKNOWN NO. 3, BOULANGERITE, GEOCRONITE, AND MENEGHINITE. THE PROPERTIES OF BOULANGERITE, GEOCRONITE, AND MENEGHINITE ARE TAKEN FROM SHORT'S DETERMINATIVE TABLES.

Properties	Unknown No. 3	Boulangerite	Geocronite	Meneghinite
Composition...	Lead sulphantimonide	$5PbS.2Sb_2S_3$	$5PbS.Sb_2S_3$	$4PbS.Sb_2S_3$
Color.....	Practically same as galena or slightly grayish	Galena white	Galena white	Galena white
Polarized light.	Strong anisot.	Strong anisot.	Strong anisot.	Anisotropic
HNO_3.....	After several seconds tarnishes dark with effervescence	Effervesces, stains black; often slow in starting	Slowly effervesces; turns black	Effervesces, stains black; usually slow in starting
HCl.....	Negative	Negative	Negative	Fumes tarnish; some areas neg.
KCN.....	Negative	Negative	Negative	Negative
KOH.....	Negative	Negative	Negative	Negative
$FeCl_3$.....	Negative	Negative	Negative	Negative
$HgCl_2$.....	Negative	Negative	Negative	Negative
Ratio of Pb : Sb	1 : 1 to 5 : 4	5 : 4	10 : 4	8 : 4

Unknown No. 4 (Fig. 8).—"A pale bluish white mineral somewhat resembling ruby silver in color. It occurs associated with tetrahedrite in galena as microscopic grains and blebs. Hardness—about that of galena; x nicols—faintly anistropic, showing a grain structure; HNO_3—neg.; HCl—neg.; KCN—tarnishes quickly iridescent to black; $FeCl_3$—nearly always neg.; $HgCl_2$—practically neg.; KOH—neg." [22]

The writer's observations are in accord with those recorded by Jewell.

A sample of unknown No. 4 was obtained by drilling out of the galena some seventy-five small grains.[23] This produced a sample that included much galena, for the grains were so small that pure material could not be isolated.

The result of the spectrographic analysis of the sample is as follows:

[22] Jewell, W. B.: *op. cit.*, p. 306, footnote 21 (4).

[23] This operation required about thirty minutes.

Pb—essential amount.
Ag— " "
Sb— " "
Cu, Zn, Fe, As, all absent.

The sulphur, which also occurs in essential amount, was detected during the process of solution of the sample. On the qualitative data above, in conjunction with the other properties, all minerals except miargyrite and pyrargyrite may be eliminated. Since these do not contain lead, the presence of this element in the unknown may be ignored, and attention confined to the silver, antimony, and sulphur. The concentrations of silver and antimony given by the spectrum are:

Ag—between N/100 and N/60, nearer N/60
Sb—between N/200 and N/100, nearer N/200.

The ratio of Ag to Sb indicated is approximately 2½ : 1. The ratio of Ag to Sb in miargyrite is 1 : 1, in pyrargyrite, 3 : 1. Therefore the mineral was identified as pyrargyrite.

SUMMARY.

A method for the use of the quartz spectrograph in the determination of ore minerals is outlined, with results of its application to a group of previously undeterminable minerals in silver-lead ores from Alaska. The results would indicate that its field of usefulness is preëminently that of obtaining data of a qualitative nature on minerals occuring in exceedingly small quantities, but that, on the other hand, approximate quantitative estimates of the elements in minerals may be made, enabling the investigator not only to recognize the major constituents but in many cases to determine their approximate ratios.

The writer desires that this paper be regarded as a statement of the present status of the investigation of a method which in his opinion holds much promise.

MINES BRANCH, DEPT. OF MINES,
OTTAWA, CANADA.

A FILM METHOD FOR STUDYING TEXTURES.

J. E. APPEL.

INTRODUCTION.

In some investigations it is important to examine the microscopic characteristics of a rock and at the same time leave the specimen intact. The grinding of thin sections not only damages the specimen, but in some cases, as in the sedimentary iron ores of the Clinton type and the sedimentary manganese and phosphate ores, the nature of the material makes their preparation difficult. Furthermore, it is well nigh impossible to obtain serial sections of sedimentary rocks close enough together to be of much value. The closest these sections can be made by sawing the rock is one to two millimeters. This paper describes a method for obtaining the textural composition of a rock by coating either a smooth or etched surface of the specimen with a nitrocellulose solution and stripping off, or peeling, the subsequently hardened film.

History of Method.—In 1906 Lagerheim suggested to Nathorst [1] the use of collodion as a method for obtaining film casts of fossil leaves and examining them for their epidermal features. Nathorst was thus able to make excellent preparations of plant remains, both silicified and imbedded in limestone tufa, as his illustrations testify. His paper also mentions the use of collodion for making copies of micrometer ocular scales from an engraved original. Nathorst's method had two inconveniences—it was difficult to make bubble-free films, and all would wrinkle on drying.

Walton [2] and Koopmans [3] greatly improved the method in 1928

[1] Nathorst, A. G.: Über die Anwendung von Kollodiumabdrucken bei der Untersuchung fossiler Pflanzen. Arkiv For. Botanik, vol. 7, no. 4, pp. 1–7, 1908.

[2] Walton, John (Koopmans, collaborater): A Method of Preparing Sections of Fossil Plants Contained in Coal Balls or in Other Types of Petrifaction. Nature, Oct. 13, 1928, p. 571.

[3] Koopmans, R. G.: Celluloidpreparat anstatt Dunnschliff, pp. 131–32. Jaarverslag over 1928, Geologisch Bureau, Nederlandsche Mijngebeid te Heerlen.

by etching the specimen with acid before coating with the nitrocellulose solution. Such treatment, by leaving a residue which is incorporated in the subsequent film, greatly accentuates the structure. Their technique, although a great improvement over Nathorst's, still included many of his difficulties. Two years later

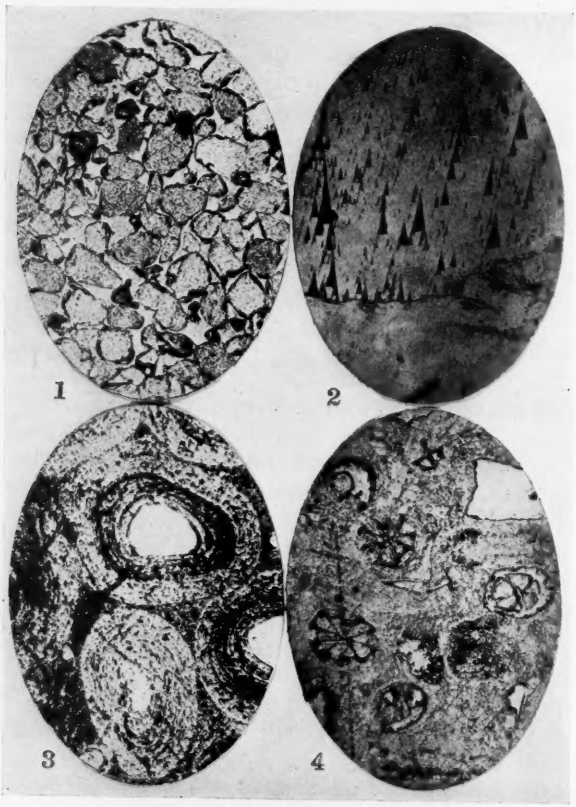


FIG. 1. Bakelite-impregnated St. Peter Sandstone. Air mount. ×40.
FIG. 2. Crystal structure in galena. Air mount. ×40.
FIG. 3. Oölitic Clinton Iron ore. Balsam mount. ×40.
FIG. 4. Fossiliferous Clinton Iron ore. Balsam mount. ×40.

Walton [4] substituted gelatin for nitrocellulose to obtain "peels" of large surfaces. This new etch method has been generally adopted by botanists in preparing substitutes for thin sections of coal balls and other plant petrifacts.

Recently Roy Graham,[5] of the University of Chicago, greatly perfected the method. His films have the following advantages: They are bubbleless, do not require the wetting of the rock with the film solvent before coating, and do not curl when left on the specimen to dry. He accomplished these improvements by using a non-hygroscopic solvent for the nitrocellulose and by adding a plasticizer to the solution. The plasticizer imparts pliability to the film and prevents it from becoming brittle with age.

Although Nathorst called attention to the possible use of the film method for studying fossils, I have been unable to discover in paleontologic literature any mention of the use of nitrocellulose. The method, however, is being utilized at Walker Museum, chiefly by Mrs. E. Hough in making serial sections of imbedded skulls and by Dr. and Mrs. C. L. Fenton in studying fossil corals.

To the economic geologist this method is of particular value in the study of soft ores from which it is difficult to prepare satisfactory polished sections or the ordinary type of thin sections. The Clinton type of iron ores responds well to this new method, the forms and structures of the oölites and organisms being well shown (see Figs. 3 and 4). Other ores that responded well to the method were the soft manganese ores and the Idaho phosphates. Sulphide ores offer more limited possibilities but the textures are brought out by inequalities in hardiness, and cleavage and the pitting dependent on cleavage show up well (Fig. 2). By treating with reagents that attack certain components only, the distribution of such components is shown in the film by the adhering powder due to their decomposition. On soft opaque ores the film strips away a thin surface layer of the specimen and preserves the detail even to color.

[4] Walton, John: Improvements in the Peel-Method of Preparing Sections of Fossil Plants. Nature, March 15, 1930, p. 413.

[5] Graham, Roy: On the Preparation of Paleobotanical Sections by the Peel Method. Stain Technology, April, 1933. (In course of publication.)

The film gives a permanent, compact, easily handled record of the specimen. It may be projected on a screen with a suitable microprojector for classroom study. Microscopic structures and textures of rocks as well as ores may thus be illustrated. Figs. 1–4 were taken of the films in transmitted light, using an ordinary petrographic microscope, and they show the usefulness of the nitrocellulose peel method for photographic purposes. They have the advantage over thin sections that their thickness is small enough to be included in the focal depth of the microscope lenses, consequently hazy outlines are avoided. Also, they do not require filters and expensive apparatus for reflected light photographs, such as are usually used in obtaining good pictures of polished ore specimens.

DESCRIPTION OF METHOD.

For studying soft opaque iron ores, manganese ores, phosphate rock, and the various rock types (particularly sedimentary rocks) the following method has been found satisfactory.

1. *Grinding.*—The specimen is ground to a plane surface and smoothed with 600F carborundum on a glass plate. If the rock is too porous or crumbly it is best to impregnate it with bakelite before grinding.

2. *Etching.*—When there is enough relief on the surface, due to inequalities in hardness, the specimen need not be etched. Also, the surface should not be etched if one is making serial sections in which the results would be obscured by the few grains usually removed with the film. Otherwise, the surface should be etched to improve the outlines. Either a 5 per cent. solution of comm. HCl or comm. HF, full strength, is used, depending on the nature of the specimen. The quality of the film is determined by the depth of etching, and as a general rule a short treatment is best. Five to thirty seconds suffices for calcareous rocks, but silicified rocks require from one to thirty minutes, and in extreme cases an hour. For ore specimens reagents that will produce insoluble salts on certain minerals should be used to produce sharp borders. When etch structure only is wanted, a few seconds of acid treatment will be sufficient. The soft manganese ores do not require

any chemical treatment at all. Phosphate rocks give best results when treated for a short time with warm HCl.

Immediately following etching, the acid should be removed by repeated dipping in water.

3. *Coating with Nitrocellulose.*—The specimen is mounted in modeling clay with its flat side level and then coated with nitrocellulose. Any of the commercial cellulose solutions can be used, but the best solution appears to be the one developed by Mr. Graham. This consists of 20 grams of 20 second gun-cotton dissolved in 200 cc. of tech. butyl acetate to which 1 cc. of a plasticizer such as dimethyl phthalate, castor oil, or tri-cresyl phosphate has been added. The phosphate plasticizer is best. Mr. Graham also adds 10 to 20 cc. of toluene or xylol, but unless one wants an easily removable film, this is unnecessary.

It may be well to point out that dry nitrocellulose is a dangerous explosive and should be dissolved as soon as possible after receiving from the manufacturer.

After distributing the solution evenly over the surface by means of a flat stick or wire, the specimen is put away to dry. The drying should not be hurried by heating at this stage. To do so results in the formation of bubbles. When two to three hours have passed and the solvent has evaporated sufficiently to leave a solid surface, the rock may be put in a warm place or may be left alone for 1 to 2 days to insure thorough drying of the film. Heating is preferable, for it will dry the film overnight. If not thoroughly dry when removed, the film will shrink by a small amount. Films on siliceous rocks need an extra long period of drying when not dried by heating. If a thicker film is desirable one can apply another coat of the solution.

4. *Removal and Mounting.*—When dry, the film is loosened around the edges and stripped with a pair of tweezers. The film may now be mounted. Heat necessary to cook balsam or melt piperine will shrink the film, consequently it should be mounted in an uncooked xylene solution of balsam which is left to harden by evaporation. This is best accomplished by putting it on a board placed on top of a radiator. It should be left on the board

for a few days with the drying temperature not exceeding 55° C. Kaiser's glycerine gelatin may be used for mounting but it requires the ringing of the cover glass with asphalt paint or other impervious material. In cases where no solid material has been incorporated in the film, liquid mounting would destroy detail. Here dry mounting is adopted. The film is placed on a slide to which a cover glass is cemented with sealing wax, asphalt paint, Venetian turpentine, or other suitable adhesive.

CONCLUSION.

This method makes possible new lines of research in sedimentology and in studying soft opaque ores, such as, for example, the soft Clinton type of ore. Moreover, soft opaque materials yield excellent films which incorporate a layer of the actual material of the specimen without loss of detail. As the illustrations show, excellent substitutes for thin sections can be made. This method has the advantage over thin sections that it is far less time-consuming and is more flexible in its application, though it is realized that it will supplement rather than replace other methods where mineral identification is of prime importance. Where texture is all that is desired, the peels are as good as thin sections, and for serial sections they are greatly superior.

DEPT. OF GEOLOGY,
UNIVERSITY OF CHICAGO,
CHICAGO, ILL.

EDITORIAL

THE AFTERMATH OF THE FIFTEENTH INTERNATIONAL GEOLOGICAL CONGRESS: AN APPRECIATION FROM SOUTH AFRICA.

REGRETTABLE as it seemed at the time, the postponement for a year of the next Congress has been of distinct service, in that it has enabled a clearer idea to be gathered of the influence of so many eminent geologists upon the advancement of general geological knowledge during the three and a half years subsequent to the fifteenth meeting.

Unquestionable, of course, have been the enormous benefits secured by the small band of geologists in Southern Africa through personal contact and debate with the pick of the geological world, who brought to bear upon our problems their collective experience. Providentially South Africa had right at hand quite a number of such conundrums, certain of which because of their remarkable or even unique character tended to run more or less counter to current ideas, evolved, as it happens, within the Northern Hemisphere. Notwithstanding, those who came to our shores were in the majority of instances fain to admit partial or complete justification for the hypotheses propounded locally.

The Bushveld Igneous Complex, the Rhodesia-Congo copper deposits, the Kimberlite pipes, the Rift Valleys of the continent—to mention only the most outstanding—each and all necessitated probings of fundamental character, and it is confidently believed that the discussions at the meetings and in the field have helped most materially not only to aid in their solution, but to induce an appreciable modification of current ideas in petrogenesis and earth structure. And this is as it should be.

But few of the visitors were able to afford the time for doing any research work on the spot. Exceptions were: Alan M. Bateman, who made a special study of the Central African copper deposits; Schneiderhöhn, Kaiser, and Kukuk, whose comprehensive, well-illustrated, joint review of the mineral deposits of South Africa contains a great amount of original matter; and Bailey Willis, of whose scientific conclusions regarding the Rift Valleys we have as yet only had glimpses. In other instances the collecting of material led to laboratory examination, as in the case of Edw. Sampson's brilliant study on the South African chromite occurrences.

A surprisingly large amount has, however, been written in the interim in various languages in the shape of reviews of the activities of the Congress and of the mineral industry of South Africa, or of particular matters or problems, thus rendering available stores of information to a far wider circle. These contributions one and all must be regarded as constituting delicate tokens of their writers' appreciation of South Africa's hospitality and friendship, and for such we in South Africa are grateful. Outstanding among such efforts is C. Freire de Andrade's able memoir on the geology and mineral resources of South Africa, which should be of immense value to all Portugese-speaking peoples. It furthermore contains an eloquent plea for the establishment of a geological survey department in Moçambique Territory, a request backed by A. J. de Freitas in his geological reconnaissance of the area to the northeast of Chinde. It is sincerely to be hoped that the Portugese Government may give effect to so admirable a proposal, Moçambique being today the only State in Southern Africa without an official survey.

To the many other able papers it is hardly possible to do justice. In tectonic geology, A. Born's analysis of the Cape Fold system is an admirable piece of work, and E. Krenkel has summarized the structures of the African continent; R. Stappenbeck has reviewed the asbestos, platinum and chromite deposits of the Union and Southern Rhodesia; G. Slater has minutely analyzed the glacial phenomena displayed by the Dwyka near Kimberley;

K. Hummel has discussed land forms and other subjects, and confirmed the secondary origin of the chert of the Great Dolomite; Z. Viktor has written about the Victoria Falls; E. Reuning has described interesting diamondiferous occurrences in Namaqualand.

H. Schneiderhöhn has investigated the platiniferous ores of the Bushveld and also the manganese deposits of Postmasburg in a penetrating mineragraphic study, and E. Kaiser has discussed their distribution and origin. The mineralized belts of Northern Rhodesia, Katanga and South-west Africa have been specially favored and knowledge thereof vastly extended by the labors of V. Babet, J. A. Bancroft, Alan M. Bateman, D. M. Davidson, V. S. Douglas, A. Gray, G. C. A. Jackson, H. Moritz, R. J. Parker, R. A. Pelletier, H. Schneiderhöhn, H. J. Schuiling, D. C. Sharpstone, and others. Quite a number of these important papers have been published in ECONOMIC GEOLOGY. Of perhaps greater moment has been the stimulus given to regular workers within Africa, which has led to much field work and many important publications, official and otherwise, but too numerous to detail. Outstanding among them is A. L. Hall's recent memoir on the unique Bushveld Igneous Complex.

The appointment of the Sub-commission of the African Surveys has resulted in the issue of the Geological Map of South Equatorial Africa on the scale of one in five million, which, although unduly generalized, marks the beginning of a new epoch in the geological investigation of the "Dark Continent."

Much has unquestionably resulted from the visit of the Congress in 1929, not a little of which has admittedly been due to the novel nature of the problems presented and to the gigantic scale of the responsible occurrences. The United States, on the other hand, is in a different position in that its territories have for so long been studied by a host of geologists; but, even so, it can hardly be doubted that geological activities within its borders will be enormously stimulated by the meeting of the Sixteenth Congress at Washington. It is therefore all the more unfortu-

nate that economic conditions should still be so unpropitious and exchange difficulties so acute.

It is nevertheless sincerely hoped that the meeting may be a most successful one and that the scientific consequences may be quite as far-reaching to the United States of America as they were to Africa in the case of the Fifteenth Congress.

ALEX. L. DU TOIT.

DISCUSSION AND COMMUNICATIONS

MOUNTING POLISHED SURFACES IN BAKELITE.

Sir: Messrs. Krieger and Bird[1] recently described an effective and inexpensive method of mounting polished surfaces in solid bakelite.

A device (Fig. 1) similar to the one described has been used successfully in the Department of Geology of the University of Colorado. The latter, however, has two advantages which may be of interest. One is the means of removing the mounted specimen from the mold and the other is the method of heating. This device was made under the direction of Dr. John W. Vanderwilt, formerly a member of the faculty and now geologist with the United States Geological Survey.

The molding sleeve (*C*) fits on the base (*D*) and the molding plunger (*B*) is inserted in the top of the molding sleeve. In order to remove the mounted specimen easily the molding sleeve (C) is made with a larger diameter than the base (*D*) and a second or auxiliary sleeve (*E*) is used which is large enough to allow the base (*D*) to pass through it but small enough to prevent the molding sleeve (C) from going through. The auxiliary

FIG. 1. Parts of mold for mounting polished sections in solid Bakelite. *A*, auxiliary plunger; *B*, molding plunger; *C*, molding sleeve; *D*, base; *E*, auxiliary sleeve.

[1] Krieger, Philip and Bird, Paul H.: Mounting Polished Surfaces in Bakelite. ECON. GEOL., vol. 27, pp. 675–678, 1932.

plunger (A) has a smaller diameter than the molding plunger (*B*) and is used to force the mounted specimen out of the mold.

The operation of the mold is as follows. The base, the molding sleeve, and the molding plunger are assembled as stated above and heated up to the proper temperature. The specimen, which has had a rough face ground on it, is placed on either the plunger or the rim of the sleeve so that it may also become heated. When these parts become hot enough they are taken apart and the flat face of the specimen is placed in contact with the top of the base (*D*). The molding sleeve (*C*) is put in place around the top of the base (*D*) and the proper amount of bakelite is poured into the top of the sleeve. The molding plunger (*B*) is inserted in the sleeve and is forced down onto the bakelite by means of a press. As long as the bakelite is flowing under this heat and pressure the plunger can be forced slightly further down. About ten minutes after all this movement ceases the molding process is complete. The molded bakelite fits the interior of the mold so snugly that it cannot be removed readily. When the mounted specimen is ready to be removed the assembled parts are placed upon the auxiliary sleeve (*E*) with the protruding part of the base (D) extending down into the hollow interior of the auxiliary sleeve and the molding sleeve (*C*) resting upon its rim. Then on top of the molding plunger (*B*), which is still in the mold, is placed the auxiliary plunger (*A*). By applying pressure or gently tapping the auxiliary plunger (*A*), the base, the mounted specimen, and the molding plunger will be forced out of the molding sleeve. The mounted specimen can then be picked up and another warmed specimen mounted immediately.

The mold is heated by means of a flat electrical heating element with a resistance of 20 ohms. This is put around the molding sleeve. A piece of sheet metal fits tightly over the sleeve; on the sheet metal is a layer of asbestos cloth for insulation; on the cloth is the heating element; the heating element is covered with another layer of asbestos cloth; on the outside another piece of sheet metal is securely bolted together. This serves to keep all these layers intact. One end of the outside layer of sheet metal is

allowed to extend out from the sleeve so that it serves as a handle. The heating element is connected to a 110 volt light circuit. One can tell when the mold has become hot enough by the method described by Messrs. Krieger and Bird, i.e. by placing a little bakelite on the base and pressing it with a knife blade or spatula. If the bakelite grains adhere to each other and the whole mass may slightly spread out while it shows no signs of charring from being too hot then the mold is at the right temperature. The temperature may also be determined roughly by removing the molding plunger and placing a thermometer inside the sleeve with the thermometer bulb resting on the top of the base. The Bakelite Corporation states that the molding temperature ranges from 149 to 154 degrees Centigrade but it has been found that a thermometer will register about ten degrees lower than this when the mold is at a good molding heat. This is probably because the thermometer does not record the true temperature of the metal. The temperature of the mold has been controlled by means of a rheostat. A rheostat resistance of 40 ohms is sufficient to prevent the mold from becoming too hot when it is assembled and not in use. A resistance of 35 ohms will keep the mold at a good heat when it is in continuous use. The heat has been controlled without the use of a rheostat by merely disconnecting and connecting the electric current by turning the switch but this is not so convenient as using a rheostat.

HARRY C. FULLER.

DEPARTMENT OF GEOLOGY,
UNIVERSITY OF COLORADO,
BOULDER, COLORADO.

ORIGIN OF BAUXITE DEPOSITS.

Sir: Reference is made to a discussion that appeared in this JOURNAL,[1] by C. H. Behre, Jr., on the origin of Arkansas bauxite. Although Behre signifies his agreement in general with the hypothesis of the origin of Arkansas bauxite advocated by Mead[2]

[1] Behre, C. H., Jr.: Origin of Bauxite Deposits. ECON. GEOL., vol. 27, pp. 678–680, 1932.

[2] Mead, W. J.: Occurrence and Origin of the Bauxite Deposits of Arkansas. ECON. GEOL., vol. 10, pp. 28–54, 1915.

eighteen years ago, he draws attention to the frequent association of lignite with bauxite and suggests the possibility that sulphuric acid and various organic acids were instrumental in bauxite formation.

The association of bauxite with lignite, and lignitic or other carbonaceous clays, is by no means confined to Arkansas. Lignite occurs with some of the bauxite deposits in Georgia and Alabama, and lignitic or other carbonaceous clays are found locally with bauxite in southern France, in the Istrian peninsula and elsewhere in Europe. Although in a few places interbedded with bauxite, the lignite and other carbonaceous deposits commonly overlie the bauxite and lead to the supposition that the conditions which resulted in lateritization and bauxitization, whatever they may have been, were followed in many places by swamp conditions which later gave place to total submergence. This succession of events appears to have been not uncommon, and if, as is generally supposed, lateritization takes place under sub-aerial conditions, it may be considered a normal sequence. However, it by no means implies any direct bearing of the carbonaceous sediments on the origin of laterite or bauxite.

Elaborating on the last statement above, it may be mentioned that most bauxite deposits overlain by lignite either now or at some period in their past history show certain well-recognized characteristics not possessed by bauxite deposits that have not been associated with lignite. These include the presence of iron in the ferrous form, either as carbonate, sulphate or sulphide, and of sulphur as iron sulphate or iron sulphide, or as aluminum sulphate. In southern Europe the term "blue" bauxite is used to designate sulphur-bearing bauxite, the blue color (taking the place of the usual dark red color of European bauxite due to the high ferric oxide content) resulting from the reduction of ferric oxide and from disseminated pyrite. In the United States siderite and pyrite crystals commonly occur in openings disseminated through bauxite underlying lignite, but they do not produce any marked change in the color,—as in the case of the southern European bauxite. A somewhat unique condition is disclosed in the central

Urals, where alunite occurs in the upper portions of deposits consisting of a mixture of bauxite, kaolin and halloysite and overlain by coal and pyrite-bearing shale and sandstone. All these phenomena are quite distinctly related to the surface portions of bauxite deposits, apparently being superimposed upon the original lateritization phenomena.

Mention may be made, also, of some chemical conditions involved in the formation of aluminum hydrate or bauxite from aluminum sulphate, as suggested by Behre's description. Aluminum sulphate is readily formed by the action of sulphuric acid on bauxite, and somewhat less readily by its action on clay or other aluminum silicates. Aluminum sulphate may be broken down into aluminum oxide and sulphur trioxide by heating to a temperature of about 770° C., but no aluminum hydrate is formed in this reaction. Moreover, intense heat is not believed to be a factor in bauxite formation, and the occurrence of lignite is in itself evidence against the presence of heat—at least subsequent to lignite formation. The process of converting aluminum sulphate to aluminum hydrate involves difficulties. The conversion might take place by reaction between aluminum sulphate and carbonates or hydrates of metals of the alkali or alkaline earth series, or zinc. These reactions, however, rarely produce pure aluminum hydrate, a considerable contamination by basic aluminum sulphate taking place. Basic aluminum sulphate, with one known exception, is completely absent from bauxite deposits, furnishing negative evidence in regard to the activity of sulphuric acid in bauxite formation. The exception is the Ural Mountains occurrence above referred to, where the presence of the basic sulphate, alunite, can readily be explained by the action of sulphuric acid on previously existing kaolin and bauxite.

As regards the action of humic or other organic acids in bauxite formation, little definite information is available. Undoubtedly some of the many organic acids prevalent in soils are active in rock decay, but to determine which of them promote kaolinization and which are concerned with lateritization will require much detailed investigation. It has been suggested to the writer that

perhaps carbon dioxide, universally present where decomposing organic matter occurs in soils, may have much to do with the solvent effects generally attributed to organic soil acids.

It may be well to remind the reader that the process of lateritization or bauxite formation is, after all, primarily one involving the removal of silica rather than the solution and redeposition of alumina. Silica is well known to be highly insoluble, as compared with bases, in waters containing inorganic acids. On the other hand, it is known to be soluble in pure water, reasonably free from acids or alkalies, and to a greater extent in carbonated alkaline waters. Should we assume that bauxite is formed by the solution and redeposition of alumina, difficulties would certainly be encountered in explaining the absence of residual silica in association with aluminum-bearing rocks such as the Arkansas nepheline syenite, the alteration of which has resulted in bauxite deposits. Moreover, the large masses of so-called "granitic-textured bauxite," pseudomorphic after nepheline syenite, could not be accounted for by any process involving the solution and removal of alumina.

The writer realizes that Behre is not proposing to explain the origin of all, or even a majority, of the bauxite deposits by the hypothesis of solution of alumina by acids and redeposition as hydrate. The preceding discussion, however, is an attempt to show that the above-suggested reactions are unlikely to take place even as secondary factors in bauxite formation.

E. C. HARDER

2900 NEW YORK CENTRAL BUILDING,
NEW YORK, N. Y.

REVIEWS

Gold Quartz Veins of the Alleghany District, California. By HENRY G. FERGUSON AND ROGER W. GANNETT. Pp. 139, pls. 58, figs. 46, U. S. Geol. Survey Prof. Paper 172, 1932. Price, $2.00.

This report is a very notable addition to the literature of economic geology. Its outstanding feature is its intensive study of the problem of the origin of the high-grade gold ore shoots, which offer the double problem of their extreme concentration of gold and their extraordinarily sporadic distribution within the veins in which they occur. The field work for the report was done in large part by Mr. Gannett, but owing to his death in 1925, the report was written wholly by Mr. Ferguson.

The Alleghany district is in the northern part of the Sierra Nevada, 20 miles west of the crest. Its gold veins are estimated to have yielded more than $20,000,000.

The oldest rocks consist of slates, schists, quartzite, chert, and greenstones. They are cut by serpentine, gabbro now saussuritic and schistose, and granite, which were all intruded presumably at or near the end of Jurassic time.

The chief veins follow minor reverse faults and were formed during a period of repeated movement along the walls. These faults appear to be auxiliary to a major reverse fault bounding the district on the east, a relation like that found by Knopf to hold along the Mother Lode system; and evidence is presented to show that the major reverse fault connects with that of the Mother Lode belt. The present outcrops are thought to be at least 10,000 feet below the surface that existed at the time the veins were formed. This conclusion is reached by way of four highly ingenious methods, which give figures ranging from 7500 to 30,000 feet. But so many hypothetical factors enter into the computations that the conclusion must be regarded as more interesting than conclusive.

Three stages of mineralization in the formation of the gold-quartz veins are recognized. During the first stage the basic rocks were serpentinized, but in view of the widespread serpentinization of the peridotites of the Sierra Nevada (to say nothing of those in the Coast Ranges) remote from quartz veins, this ascription of serpentinization to the vein-forming solutions seems an unnecessary hypothesis. In stage two the veins were largely filled with quartz and some pyrite and arsenopyrite, and favorable

wall rocks were replaced by albite. In stage three the gold was introduced; it was deposited chiefly by replacement along fractures in the older quartz filling of the veins, together with carbonate, mica, graphite, and sulphides; and the wall rocks were replaced by ankerite, mariposite, and sericite.

The most remarkable feature of the district is the extreme localization of the gold in short high-grade shoots. A single shoot yielded nearly $1,000,000 from roughly 3000 cubic feet of quartz. Outside the shoots the quartz is either low-grade or barren, and the change from high-grade to barren is often startlingly abrupt. Since some of the veins are 1000 feet long and 55 feet thick at a maximum, the problem of the extreme localization of the gold in them is of extraordinary interest.

Features favorable to the occurrence of high-grade shoots are vein junctions, shattering of the quartz, and the presence of serpentine. The serpentine is favorable because it has deflected the courses of the veins, and such places were likely to be specially fractured during later movements along the vein walls. Most of the gold so far obtained was closely associated with arsenopyrite, partly as replacement of the arsenopyrite but mostly as replacement of the quartz in contact with the arsenopyrite. The ultimate origin of the gold ore-shoots would then be dependent on the origin of the shoots of arsenopyrite.

That the arsenopyrite was a precipitant of the gold is thought to be established by the work of Palmer and Bastin.[1] This is not necessarily so, for Palmer and Bastin worked with solutions in which the gold was present as a positive ion, and not with solutions in which the gold was present in a negative complex ion, as for example in the aurocyanide ion $\{Au(Cn)_2\}$, and no one has yet established in what ionic form gold was transported in hydrothermal ore-forming solutions. In his first paper on the Alleghany district the author[2] concluded that the arsenopyrite determined the loci of deposition of the gold carried up by later solutions, but he now believes "that the change of composition of the gold-bearing solution upon dissolving the quartz compelled the deposition of the gold."

Except for the chromium in the mariposite, whose derivation from the serpentine appears well-established, none of the other elements in the veins or altered walls appears to have been derived from the wall-rocks, although the author rather inclines to the belief that the gold was derived from the serpentine wall-rocks.

The judicial attitude which the author holds toward the many enigmatic problems that have arisen during this extended investigation is well

[1] Palmer, Chase, and Bastin, E. S.: Metallic Minerals as Precipitants of Silver and Gold. ECON. GEOL., vol. 8, p. 156, 1913.

[2] Lode Deposits of the Alleghany District, California. U. S. Geol. Survey Bull. 580, p. 170, 1915.

exemplified by his frank avowal that he has found "no acceptable explanations for the peculiar concentration of the gold in high-grade shoots or for the fact that the gold, though associated with minerals that have replaced the wall-rock, is always found in association with the earlier quartz." The close association of the gold with the main quartz filling of the veins, extremely close in spite of the fact that the gold was introduced much later than the deposition of the quartz, is indeed a remarkable enigma. It suggests that possibly there is a germ of truth in Hatschek and Simon's suggestion that the gold in gold-quartz veins was originally deposited in disperse form in the quartz and was later assembled in visible form.

The report closes with an optimistic forecast of the future of the district, and the possibility is indicated that it will produce an additional $56,000,000. In conclusion, this report proves to be highly stimulating reading and represents the most sustained attack upon the problems presented by gold-quartz veins that has yet been made.

ADOLPH KNOPF.

Tabellen zur Berechnung von Mineral- und Gesteinsanalysen. By H. VON PHILIPSBORN. Pp. vi + 313. Akademische Verlagsgesellschaft M. B. H., Leipzig, 1933. Price, $7.00.

It might at first thought be supposed that the numerous tables that have already been established to aid in the calculation of rock analyses in terms of minerals would suffice for most students of mineralogy and petrography. But an examination of Philipsborn's tables soon indicates that the expansion of such tables beyond the limits heretofore deemed satisfactory is of immensely increased value to mineralogists and of extreme value to economic geologists. They are more comprehensive than earlier tables and are much more accurate, since they are based on precise, and not approximate, atomic and molecular weights. They embrace the consideration of all atoms and atomic groups which are necessary for the calculation of all important minerals, ores, salts, and siliceous and carbonate rocks. They may be used in the determination (1) of molecular proportions from the percentages by weight in chemical analyses, (2) of the normative minerals of rocks from the percentages by weight in rock analyses, (3) of percentages by weight of the isomorphous molecules in mixed crystals from the percentages of constituents found by analysis, (4) of the chemical composition (i.e. the percentages by weight of the usual chemical constituents) from the percentages by weight of the minerals in mineral aggregates, and (5) of percentages by weight of the minerals in an aggregate where their percentages by volume are known, or the reverse.

There is added to the tables used in calculation a final list showing the theoretical composition of the pure simple minerals and of the pure components in isomorphous mixtures, numbering in all 419.

The volume will prove a boon to those who find it necessary to do much calculating of the kinds indicated above.

W. S. BAYLEY.

American Institute of Mining Engineers Series. 4 vols. McGraw-Hill Book Co., New York, 1932. Price, $2.50 each.

1. **A History of American Mining,** by T. A. RICKARD. First edition, pp. 419, figs. 26. No one is better fitted than Mr. Rickard to write a history of American mining. In his inimitable style he sets forth a fascinating story of early mining and its development, scholarly, as would be expected of him, but not pedantic or heavy. It reads as lightly as a good novel, and is as interesting. His 18 chapters deal with different mining developments, as, for example, The Beginning; The Gold Discoveries; The Comstock Lode; The Great Salt Lake; The Copper of Lake Superior; The U. V. X., a Mining Adventure; The Great Diamond Hoax.

It is a volume that should not only be in the library of every mining man and geologist, but be read through from cover to cover.

2. **The Examination of Prospects; A Mining Geology,** by C. G. GUNTHER, revised by R. C. FLEMING. 2d edit. Pp. 220, figs. 65.

The first edition of this book is already favorably known to geologists and mining engineers. Its revision is appropriate. The author's experience and statements have been retained, and the revision includes important new data regarding the porphyry coppers, Canada, Rhodesia, Alaska, and new developments in the United States. The chapter headings indicate its contents: Mining Examinations; Structural Geology; Structural Features of Ore Deposits; Primary Ores and Types of Primary Deposits; Ore Shoots; Primary Alteration of Wall Rocks; Alterations by Surface Agencies; Residual Ores and their Distribution; Secondary Ores and Ore Shoots; Outcrops. The content has been brought up to date and the revision appears to be able and thorough. The book is especially valuable for the young engineer and geologist.

3. **Mineral Economics:** Lectures under the Auspices of the Brookings Institution, by 15 authors. Edited by F. G. TRYON AND E. C. ECKEL. First edition, pp. 311, figs. 31.

This valuable volume embodies a series of addresses relating to different fields of mineral economics, by experts in each subject. The subjects are: An Outline of the Field, by F. G. Tryon and F. E. Berquist; Geographic Distribution of World Production, by J. W. Frey; Cycles of Mineral Production, by D. F. Hewett; Exploration and Discovery, by C.

K. Leith; Natural Gas, by E. B. Swanson; Copper, by C. E. Julihn; Fertilizers and Substitutes, by R. S. McBride; Rise of Scrap Metals, by H. F. Bain; Strategic Minerals in War and Peace, by E. C. Eckel; Tariffs and Exhaustible Resources, by J. W. Furness; Mine Taxation, by T. T. Read; Production Control in Petroleum, by L. Logan; Precious-Metal Supplies and Price Level, by G. F. Loughlin; Future Value of Mineral Property, by J. R. Finlay. The component parts are well written and carefully edited, and constitute a valuable contribution to this broad subject.

4. **Choice of Methods in Mining and Metallurgy,** by eleven authors. First edition, pp. 178.

Eleven articles dealing with problems of the mining and metallurgy of metal, coal, and oil. Designed to help one in making engineering decisions. They are stimulating and helpful.

Proceedings of the Third International Conference on Bituminous Coal. 2 vols. Pp. 965 and 1034. Carnegie Inst. of Technology, Pittsburgh, Pa., 1932.

These two volumes consist of 98 papers, with discussions, presented to the meeting held in Pittsburgh in November, 1931. The various papers are arranged under the following heads: General, Economics, Competition between Fuels, Low and High Temperature Carbonization, Coal Carbonization Problems, Gasification, By-Products, Hydrogenation and Liquefaction; Railway, Steamship, Domestic, Power Plant, and Pulverized, Fuels; Smoke and Dust Abatement, Preparation, Coal Cleaning, Origin and Classification, and Steam Purification.

The list of titles is impressive, and they appear to cover the whole range of modern thought and technology in connection with coal.

BOOKS RECEIVED.

By

DAVID GALLAGHER.

Text Book of Geology: Part I, Physical Geology. By C. R. Longwell, A. Knopf, R. F. Flint. Revised. Pp. 513, figs. 341. John Wiley & Sons, New York, 1932. Price, $3.75. A complete revision of this well known elementary text. (To be reviewed later.)

Geology. By W. H. Emmons, G. A. Thiel, C. R. Stauffer and I. S. Allison. First edition. Pp. 514, figs. 478. McGraw-Hill Book Co., New York, 1932. Price, $4.00. An excellent new elementary text. (To be reviewed later.)

Sands, Clays and Minerals (A. L. Curtis, Chatteris, England) in No. 3 (Jan. 1933) of its first volume contains a valuable article on "British Coals," illustrated by colored plates.

The Story of a Billion Years. By W. O. HOTCHKISS. Pp. 137. Century of Progress Series, Williams & Wilkins, Baltimore, 1932. Price, $1.00. A popular book, well written, which deals lightly with the surface features, the origin and the age of the earth, records of life, past climates, ice ages, and natural resources.

The Eastern Portion of Mount McKinley National Park. By S. R. CAPPS. The Kantishna District and Mining Development in the Tatlanika and Totatlanika Basins. By F. H. Moffit. Pp. 126, pls. 3, figs. 5. U. S. Geol. Surv. Bull. 836–D. Washington, 1932. Price, 35 cents. Contains geological reconnaissance map of central Alaska, 1/250000, full color.

Recent Natural Gas Developments in South-Central New York. By D. H. NEWLAND AND C. A. HARTNAGEL. Pp. 20, figs. 3. New York State Mus., Circular 7. Albany, 1932. Wayne-Dundee and Tioga fields producing from Oriskany sandstone.

The Prospects for Gold Discoveries in New York State. By D. H. NEWLAND. Pp. 6. New York State Mus., Circular 12. Albany, 1933. Timely warning to optimists.

Mining and Quarry Industries of New York for 1927 to 1929. Review of the Natural Gas and Petroleum Developments in New York State. By D. H. NEWLAND AND C. A. HARTNAGEL. Pp. 184, figs. 2. New York State Mus. Bull. 295. Albany, 1932.

Earthquake Risks in Arkansas. By G. C. BRANNER AND J. M. HANSELL. Pp. 13, pls. 4, tables 4. Arkansas Geol. Surv., Information Circular 4. Little Rock, 1933. Price, 60 cents. Statistical study of earthquakes of the region since 1811.

Petroleum: A Selected Bibliography. 2d Ed., Revised. By M. E. HOYT. Pp. 63. Colorado School of Mines Quarterly, vol. 27, No. 4. Golden, 1932.

Mining Industry of Idaho for the Year 1932. By S. CAMPBELL. Pp. 303, figs. 34th Annual Report of the Inspector of Mines. Boise, 1933.

Die Erdgeschichte als Phasenbild der Allgemeinen kosmischen Abkühlung. By F. WIRTHS. Pp. 83. Wilhelm Knapp, Halle (Saale), 1933. An attempt to correlate orogenesis, volcanology, past climates, etc., with a cooling Earth.

Technische Grundlagen des Tagebaues, I, 1: Gewinnung. By A. OHNESORGE. Pp. 232, figs. 282, tables 69. Wilhelm Knapp, Halle (Saale), 1933. Price, 25.50 RM. Drilling, blasting, and especially excavation machinery.

Platina I Sulfidisk Nikkelmalm. By S. FOSLIE AND M. J. HØST. Pp. 71, figs. 3, pls. 5. Norges Geologiske Undersökelse, No. 137. Oslo, 1932.

SCIENTIFIC NOTES AND NEWS

W. L. Whitehead has recently been elected a director of the Montezuma-Apex Mining Company, operating subsidiary of Utah-Apex in California.

H. A. Buehler, of Rolla, Missouri, was tendered a testimonial dinner on May 10, the occasion being his twenty-fifth anniversary as State Geologist of Missouri.

A. L. Hall, who recently retired as assistant director of the Geological Survey of the Union of South Africa, has been appointed to represent the Union Government as official delegate to the International Geologic Congress at Washington.

Sir John Cadman has been awarded the Gold Medal of the Institution of Mining and Metallurgy, London, in recognition of his work in the development of the mineral industries and in the advancement of technical education.

Alpheus Williams has left Cape Town, Africa, for a six months' visit to England.

Waldemar Lindgren, professor of economic geology at the Massachusetts Institute of Technology since 1912, and before that chief geologist of the U. S. Geological Survey, is retiring at the end of the school year, at the age of 73.

F. E. Keep is the new president of the Geological Society of South Africa.

A. L. Du Toit has been awarded the Draper Memorial Medal by the Geological Society of South Africa.

M. E. Hurst, of the Ontario Department of Mines, is to make an examination during the summer of underground conditions at the Howey Mine, and will investigate claims in the Red Lake camp.

Oscar H. Hershey, of San Francisco, California, recently made a trip to Canada for mine examination.

G. Townsend Harley, formerly located at Clifton, Arizona, is now geologist for the New Mexico Bureau of Mines at Socorro.

A. W. Allen, of the Engineering and Mining Journal, is to become editorial representative of the McGraw-Hill Company in London.

S. J. Truscott, professor of mining at the Royal School of Mines, London, has been visiting mining districts in Canada and the United States.

F. B. Plummer, of the Bureau of Economic Geology, University of Texas, has been elected president of the Society of Economic Paleontologists and Mineralogists.

Guy N. Bjorge, of the Homestake Mines staff and formerly chief geologist at Old Dominion Globe, Arizona, has been making a visit to Arizona.

Harrison Schmitt has changed his headquarters from El Paso, Texas, to Hanover, New Mexico, where he is doing geological work for the Black Hawk Mining and Milling Company.

W. A. Pretyman, for thirteen years Secretary of Mines in Tasmania, has resigned, and J. B. Scott, State Mining Engineer, will take his place.

The American Association of Petroleum Geologists has elected officers as follows: president, Frank R. Clark, chief geologist, Mid-Kansas Oil and Gas Company; secretary-treasurer, William B. Heroy, vice-president of the Sinclair Exploration Company; Association editor, L. C. Snider, chief geologist for Henry L. Doherty & Company.

The annual meeting of the Society of Economic Geologists will take place at Princeton, N. J., on July 7–8, just prior to the excursions that precede the International Geologic Congress meetings. This meeting will for the first time give opportunity for foreign members of the Society to be in attendance, and it is hoped that as many as possible will plan to attend. Interested members of the International Congress who may not be members of the Society are cordially invited to attend this meeting.

At the conclusion of the meeting D. H. McLaughlin will take up the duties of Secretary, as successor to Edward Sampson, who has given freely of his time and effort during a difficult period in the life of the Society.

INTERNATIONAL GEOLOGIC CONGRESS.

Preparations are now being completed for the sessions of the International Geologic Congress in Washington, and it is hoped that all who have not yet sent in their applications for membership will do so without delay. Those who cannot attend the sessions in person will find it advantageous to subscribe for a membership ($5.00), which will entitle them to a complete set of the valuable guidebooks that have been published, and a geologic map of the United States. All libraries should likewise take advantage of this opportunity.

Copies of books mentioned under "Reviews" or under our "New Book List" (see advertisement page) may be purchased through our Journal Bookshop by writing to W. S. Bayley, University of Illinois, Urbana, Ill.